RT3000

Inertial and GPS Measurement System

User Manual

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Introduction

The RT3000 family of Inertial and GPS Navigation Systems from Oxford Technical Solutions are instruments for making precision measurements of motion in real-time.

To obtain high precision measurements, the RT3000 uses mathematical algorithms developed for use in fighter aircraft navigation systems. An inertial sensor block with three accelerometers and three gyros (angular rate sensors) is used to compute all the outputs. A WGS-84 modelled Strapdown Navigator Algorithm compensates for earth curvature, rotation and Coriolis accelerations while measurements from high-grade kinematic GPS receivers update the position and velocity navigated by the inertial sensors.

This innovative approach gives the RT3000 several distinct advantages over systems that use GPS alone:

- The RT3000 has a high, 100Hz update rate and a wide bandwidth.
- The outputs are available with very low, 3.9ms latency.
- All outputs remain available continuously during GPS blackouts when, for example, the vehicle drives under a bridge.
- The RT3000 recognises jumps in the GPS position and ignores them.
- The position and velocity measurements that the GPS makes are smoothed to reduce the high-frequency noise.
- The RT3000 makes many measurements that GPS cannot make, for example acceleration, angular rate, heading, pitch, roll, etc.
- The RT3000 takes inputs from Wheel-Speed in order to improve the drift rate when no GPS is available.

The standard RT3000 system processes the data in real-time. The real-time results are output via an RS232 serial port, over 10/100 Base-T Ethernet using a UDP broadcast and, optionally, on CAN bus. Outputs are time-stamped and refer to GPS time; a 1PPS timing sync can be used to give very accurate timing synchronisation between systems. The inertial measurements are synchronised to the GPS clock.

Internal data logging enables the data to be reprocessed post-mission. Data can be collected in the unit, downloaded using “ftp”, processed on the PC and viewed using customer’s software.

Easy Operation

Installation and operation of the RT3000 could not be simpler. There is minimal configuration required to use the system. The configuration can be saved to the RT3000 so it can operate autonomously without user intervention. A lot of work has been put into the initialisation of the inertial algorithms so that the RT3000 can reliably start to navigate in the vast majority of situations.

The single unit contains the inertial sensors, GPS receiver, data storage and CPU. One or two antennas need to be mounted outside the vehicle where they have a clear view of the sky. 9 to 18Vd.c. power can be obtained from most vehicles' power supplies. A laptop computer allows real-time viewing of the results.

Self-Correcting

Unlike conventional Inertial Navigation Systems, the RT3000 uses GPS to correct all its measurements. GPS makes measurements of position, velocity and (for dual-antenna systems) heading. But, using these measurements, the RT3000 is able to keep other quantities, such as roll and pitch, accurate. There is no drift from the RT3000 in any of the measurements while GPS is present.

RT3000 Family Variants

The RT3000 product family includes several different products based on the same technology. Each product has been selected to serve a different accuracy requirement or operating condition. The family is split between single antenna systems and dual-antenna systems.

The advanced algorithm in the RT3000 software means that most road vehicle customers are able to use a single antenna system. The *Heading Lock* and *Advanced Slip* features mean that the RT3000 can maintain accurate heading while stationary and while driving with low vehicle dynamics.

Applications on aircraft or at sea may require a dual-antenna system to maintain high accuracy heading.

Single Antenna Models

The single antenna models can be used in the vast majority of situations. See the dual-antenna section for details of where the dual-antenna systems will provide an advantage.

The single antenna models are as follows:

- RT3200 – Differential GPS with positioning accuracy to 1.0m CEP using a suitable differential source, or 3.0m CEP with no differential corrections.
- RT3100 – Differential GPS with positioning accuracy to 0.4m CEP using a suitable differential source, or 1.8m CEP with no differential corrections.
- RT3020 – L1 Kinematic GPS with positioning accuracy to 20cm RMS.
- RT3002 – L1/L2 Kinematic GPS with positioning accuracy to 2cm RMS.
- RT3080 – SBAS-L2 with positioning accuracy to 80cm CEP.
- RT3050 – OmniStar VBS Enabled with positioning accuracy to 50cm CEP.
- RT3040 – OmniStar HP Enabled with positioning accuracy to 10cm CEP.

(See section later on for more information on SBAS and OmniStar).

The lower specification systems can be upgraded to a higher specification through a GPS receiver software upgrade and use of the correct base-station. The Single Antenna models can also be upgraded to dual-antenna (unless the small box option has been specified, in which case the second GPS card does not fit).

Dual Antenna Models

With a dual antenna RT3000 product the system uses the difference in position between the two antennas to keep heading accurate.

Dual antenna systems are recommended for road vehicle testing on low-friction surfaces (e.g. ice), aerial survey and marine use (ships, survey vessels). GPS-only dual-antenna systems require open-sky environments to operate because they can take several minutes to acquire heading lock. Advanced processing in the RT3000 allows relock to occur after 5s of a sky-obstruction; in this time the RT3000's heading will not have significantly decreased. The fast relock time is made possible because the RT3000's own heading is used resolve the ambiguities in the GPS measurements. Resolution of these ambiguities is what normally takes several minutes. The heading software in the RT3000 enables significantly better performance and coverage compared to GPS-only solutions.

The dual antenna models are as follows:

- RT3102 – Differential GPS with position accuracy to 0.4m using a suitable differential source.
- RT3042 – OmniStar VBS Enabled with positioning accuracy to 50cm CEP.
- RT3052 – OmniStar HP Enabled with positioning accuracy to 10cm CEP.
- RT3022 – L1 Kinematic GPS with position accuracy to 20cm RMS.
- RT3003 – L1/L2 Kinematic GPS with position accuracy to 2cm RMS.

The lower specification systems can be upgraded to a higher specification through a GPS receiver software upgrade and use of the correct base-station.

Satellite Differential Corrections

To improve the positioning accuracy of the standard GPS two satellite based differential correction services are available. These are WAAS (or EGNOS) and OmniStar.

SBAS services, such as WAAS and EGNOS, are wide area differential corrections provided for free. They provide an accuracy of about 1.2m CEP. This service is only available reliably in North America. The European version exists but cannot be used with any confidence.

OmniStar is a subscription service. The RT3000 systems that have OmniStar capability include the necessary hardware to receive the OmniStar corrections. In addition to this it is necessary to pay OmniStar a license fee to activate the corrections. OmniStar

provides two levels of correction. These are VBS (Virtual Base Station) and HP (High Performance).

For more information on OmniStar see the OmniStar web site, www.omnistar.com.

Scope of Delivery

Table 1, below, lists all the items that are delivered with each RT3000 model.

Table 1. Summary of the RT3000 System Components

Qty	Description	RT3200	RT3100	RT3020	RT3002	RT3102	RT3022	RT3003	RT3050	RT3040	RT3080
Vehicle Components											
1	RT3000 System Unit	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
1	User Cable[1] (14C0038A)		✔	✔	✔	✔	✔	✔	✔	✔	✔
1	Low Cost User Cable	✔									
1	GPS Antenna AT575-70	✔	✔	✔		x2	x2				
1	GPS Antenna AT2775-12				✔			x2			✔
1	GPS-600-LB Antenna								✔	✔	
1	5m TNC-SMA Cable				✔			x2	✔	✔	✔
1	Null Modem Serial Cable	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Accessories											
1	CD-ROM with Manual and Software	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
1	RT3000 User Manual	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Note 1: Several different user cables are available. A different cable may be chosen by the customer. Custom cables are also made. See drawings at the end of the manual for cable specifications.

All the 20cm and 2cm products require the correct Differential Corrections in order to work to their full specification. Differential Corrections can be supplied by an RT-Base unit, or other suitable Differential Correction source. See the manual on the RT-Base for details on the Scope of Delivery for the RT-Base.

In addition to the components supplied the user will require a laptop computer or another logging system.

Figure 1. Typical RT3000 system in transit case.

Note that the antenna style has changed since this picture was taken.

Warranty

Oxford Technical Solutions Limited warrants the RT3000 products to be free of defects in materials and workmanship, subject to the conditions ser forth below, for a period of one year from the Date of Sale.

'Date of Sale' shall mean the date of the Oxford Technical Solutions Limited invoice issued on delivery of the product. The responsibility of Oxford Technical Solutions Limited in respect of this warranty is limited solely to product replacement or product repair at an authorised location only. Determination of replacement or repair will be made by Oxford Technical Solutions Limited personnel or by personnel expressly authorised by Oxford Technical Solutions Limited for this purpose.

In no event will Oxford Technical Solutions Limited be liable for any indirect, incidental, special or consequential damages whether through tort, contract or otherwise. This warranty is expressly in lieu of all other warranties, expressed or implied, including without limitation the implied warranties of merchantability or fitness for a particular purpose. The foregoing states the entire liability of Oxford Technical Solutions Limited with respect to the products herein.

Specification

The specification of the products is listed in Table 2, Table 3 and Table 4. These specifications are listed for operation of the system under the following conditions:

- After a warm-up period of 15 minutes continuous operation.
- Open sky environment, free from cover by trees, bridges, buildings or other obstructions. The vehicle must have remained in open sky for at least 5 minutes for full accuracy.
- The vehicle must exhibit some motion behaviour. Accelerations of the unit in different directions are required so that the Kalman filter can estimate the errors in the sensors. Without this estimation some of the specifications degrade.
- The distance from the system to the GPS (primary) antenna must be known by the system to a precision of 5mm or better. The vibration of the system relative to the vehicle cannot allow this to change by more than 5mm. The system will estimate this value itself in dynamic conditions.
- For dual-antenna systems the relative orientation of the two antennas must be known to the system to 0.05° or better. The system will estimate this value itself under dynamic conditions.
- For single antenna systems the heading accuracy is only achieved under dynamic conditions. Under benign conditions, such as motorway driving, the performance will degrade. The performance is undefined when stationary for prolonged periods of time.

Optionally extended measurement ranges covering 30G acceleration and 300°/s angular rate may be requested. The specification using the extended measurement range sensors can be marginally worse than those listed here.

Table 2. Performance Specification for the RT3000 Single Antenna Systems

Product	RT3002	RT3020	RT3100	RT3200
Positioning	L1/L2 Kinematic	L1 Kinematic	SPS / DGPS / SBAS	SPS / DGPS / SBAS
Position Accuracy	1.5mCEP SPS 1.2m CEP SBAS 2cm 1σ	1.8mCEP SPS 1.2m CEP SBAS 20cm 1σ	1.8mCEP SPS 1.2m CEP SBAS 0.4mCEP DGPS	3.0mCEP SPS 1.4m CEP SBAS 1.0mCEP DGPS
Velocity Accuracy	0.05 km/h RMS	0.08 km/h RMS	0.1 km/h RMS	0.2 km/h RMS
Acceleration – Bias – Linearity – Scale Factor – Range	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²
Roll/Pitch	0.03° 1σ	0.04° 1σ	0.05° 1σ	0.2° 1σ
Heading	0.1° 1σ	0.1° 1σ	0.1° 1σ	0.2° 1σ
Angular Rate – Bias – Scale Factor – Range	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.02°/s 1σ 0.2% 1σ 100°/s
Track (at 50km/h)	0.07° RMS	0.1° RMS	0.15° RMS	0.2° RMS
Slip Angle (at 50km/h)	0.15° RMS	0.15° RMS	0.2° RMS	0.3° RMS
Lateral Velocity	0.2%	0.2%	0.2%	0.35%
Update Rate	100 Hz			
Calculation Latency	3.9 ms			
Power	9-18 V d.c. 15W			
Dimensions (mm)	234 x 120 x 80			
Weight	2.2 kg			
Operating Temperature	–10 to 50°C			
Vibration	0.1 g²/Hz 5-500 Hz			
Shock Survival	100G, 11ms			
Internal Storage	500 MB			
Twin Antenna	No	No	No	No
Upgradeable GPS	Yes (RT3003)	Yes	Yes	Yes

Note: The single antenna units may be supplied in a smaller box, with a single antenna port. The dimensions are 243 x 108 x 68mm and the weight is 2.1kg. This box does not allow the single antenna system to be easily upgraded to dual antenna.

Table 3. Performance Specification for the RT3000 Differential Systems

Product	RT3040	RT3050	RT3080
Positioning	OmniStar HP	OmniStar VBS	SBAS-L2
Position Accuracy	10cm CEP[1]	50cm CEP	1.8m CEP SPS 0.8m CEP SBAS
Velocity Accuracy	0.07 km/h RMS	0.08 km/h RMS	0.1 km/h RMS
Acceleration – Bias – Linearity – Scale Factor – Range	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²
Roll/Pitch	0.03° 1σ	0.04° 1σ	0.05° 1σ
Heading	0.1° 1σ (dynamic)	0.1° 1σ (dynamic)	0.1° 1σ (dynamic)
Angular Rate – Bias – Scale Factor – Range	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s
Track (at 50km/h)	0.08° RMS	0.1° RMS	0.15° RMS
Slip Angle (at 50 km/h)	0.15° RMS	0.15° RMS	0.2° RMS
Lateral Velocity	0.2%	0.2%	0.2%
Update Rate		100 Hz	
Calculation Latency		3.9 ms	
Power	9-18 V d.c. 20W	9-18 V d.c. 20W	9-18 V d.c. 15W
Dimensions (mm)		234 x 120 x 80	
Weight	2.4 kg	2.4 kg	2.2 kg
Operating Temperature		–10 to 50°C	
Vibration		0.1 g²/Hz 5-500 Hz	
Shock Survival		100G, 11ms	
Internal Storage		500 MB	
Twin Antenna	No	No	No
Upgradeable GPS	No	Yes	Yes

Note 1: For OmniStar HP continuous sky may be required for a long period of time (30 minutes or more) before the accuracy achieves 10cm. The OmniStar HP service can achieve this in complete open-sky and airborne applications.

Table 4. Performance Specification for the RT3000 Dual Antenna Systems

Product	RT3003	RT3022	RT3102
Positioning	L1/L2 Kinematic	L1 Kinematic	SPS / DGPS / SBAS
Position Accuracy	1.5m CEP SPS 1.2m CEP SBAS 2cm 1σ open sky	1.8m CEP SPS 1.2m CEP SBAS 20cm 1σ open sky	1.8m CEP SPS 1.2m CEP SBAS 0.4m CEP DGPS
Velocity Accuracy	0.05 km/h RMS	0.08 km/h RMS	0.1 km/h RMS
Acceleration – Bias – Linearity – Scale Factor – Range	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²	 10 mm/s² 1σ 0.01% 0.1% 1σ 100 m/s²
Roll/Pitch	0.03° 1σ	0.04° 1σ	0.05° 1σ
Heading	0.1° 1σ	0.1° 1σ	0.1° 1σ
Angular Rate – Bias – Scale Factor – Range	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s	 0.01°/s 1σ 0.1% 1σ 100°/s
Track (at 50km/h)	0.07° RMS	0.1° RMS	0.15° RMS
Slip Angle (at 50 km/h)	0.15° RMS	0.15° RMS	0.2° RMS
Lateral Velocity	0.2%	0.2%	0.2%
Update Rate		100 Hz	
Calculation Latency		3.9 ms	
Power		9-18 V d.c. 20W	
Dimensions (mm)		234 x 120 x 80	
Weight		2.4 kg	
Operating Temperature		–10 to 50°C	
Vibration		0.1 g²/Hz 5-500 Hz	
Shock Survival		100G, 11ms	
Internal Storage		500 MB	
Twin Antenna	Yes	Yes	Yes
Upgradeable GPS	No	Yes	Yes

Environmental Protection

The RT3000 is rated to IP65. To achieve IP65 it is necessary to have connectors fitted to both TNC Antenna Connectors and to use self-amalgamating tape over the TNC connectors.

Quick Guide to Operation

The basic operation of the RT3000 products is simple. The following steps should be taken to operate the units.

1. Fit the RT3000 system to the vehicle with the cable connections facing the rear of the vehicle. The LEDs should be to the left and the antenna connections to the right for normal, level operation.

2. Connect the User Cable (14C0038A) to the RT3000.

Figure 2. RT3000 System in vehicle

3. Connect the GPS Cable to the RT3000. For quick operation of dual antenna models connect to the primary (top) antenna connection and do not use the secondary antenna. Refer to the section on the secondary antenna for additional information on using the secondary antenna.

4. Connect the GPS Cable to the GPS antenna.

5. Secure the GPS antenna on the top of the vehicle where it has a clear view of the sky and is not obstructed at any angle by masts, aerials or other high objects. For best results before configuration of the RT3000 system try to keep the antenna roughly above the RT3000 system. (The RT3000 system will be delivered expecting the antenna to be 1m above the RT3000 unit with no X- or Y-axis displacement; it will assume that these measurements are accurate to about 1m).

6. Use the Null Modem Cable to connect J2 of the User Cable (14C0038A) to a serial port on a laptop computer. Run the program ENGINUITY.EXE (it can be run directly from the CD).

7. Apply power to the RT3000. The bottom LED will turn green to show that power has been applied. Wait for the top LED to flash red – this will happen when the operating system has booted and will take about 30 seconds. Wait for the top LED to turn permanently red – this will happen when the GPS receiver has found sufficient satellites to provide valid time, position and velocity and will take between 60 seconds and 20 minutes from power-on. (It is very rare for the GPS to take 20 minutes to find satellites; the typical lock time is less than 90 seconds, though if the unit has just been shipped from another part of the world then lock-time will increase).

8. Accelerate gently on a forward direction. The system will initialise and start to output data once the speed of the vehicle exceeds about 5 m/s (10 km/h). The top LED will turn orange (when real-time data is not yet available) and then turn green (after 10 seconds when the outputs are real-time and the latency is to specification).

The RT3000 is now operating. Fully specification will not be achieved within the first 15 minutes of operation. During this time dynamic vehicle manoeuvres will help the system achieve full specification.

Initialisation Process

Before the RT3000 can start to output all the navigation measurements it needs to initialise itself. Before it can initialise itself it needs to have all the measurements listed in Table 5, below.

Table 5. Quantities required for Initialisation

Quantity	Description
Time	Measured by internal GPS
Position	Measured by internal GPS
Velocity	Measured by internal GPS
Heading	Approximated to Course over Ground when the vehicle moves with large error. (Some Dual-Antenna systems can initialise when stationary)
Roll, Pitch	Vehicle Level option: Assumed zero with a large error Otherwise: Estimated over first 40s of motion with large error.

The system will start when it has estimates of all of these quantities. Course over Ground will be used to as the initial Heading when the system exceeds 5m/s (18kmh, about 11mph). If the system is mounted level in the vehicle then the Vehicle Level option will enable the system to start immediately. Otherwise the system requires about 40s to find approximate values for Roll and Pitch.

For the initialisation process to work correctly, the system requires the user to tell it which way it is mounted in the vehicle, otherwise the Course over Ground will not be close enough to the Heading.

Real-Time Outputs

During the initialisation process the system runs 1 second behind so that the information from the GPS can be compared to the information from the inertial sensors. After initialisation the system has to "catch-up" this one second lag. It takes 10 seconds to do this, during the first 10 seconds the system cannot output data in real-time, the delay decays to the specified latency linearly over this 10 second period.

The user can identify that the outputs are not real-time because the Strapdown Navigator State LED is orange. When the system is running it real-time this LED is green.

Warm Up Period

During the first 15 minutes of operation the system will not conform to the specification. During this period the Kalman Filter runs a more relaxed model for the sensors. By running a more relaxed model the system is able to:

1. Make better estimates of the errors in the long term (if it does not get these correct then they become more difficult to correct as time goes on).

2. Track the errors in the inertial sensor during their warm-up period (when their errors change more quickly than normal).

During this period it is necessary to drive the vehicle, otherwise the errors will not be estimated and the specification will not be reached. The NCOM output message (and the CAN outputs) includes status information that can be used to identify when the required specification has been met.

System Outputs

The system can output data on two serial ports and over Ethernet; if the CAN bus option is selected then the second serial output is replaced by the CAN bus output. The outputs are available on the standard cables as follows:

Table 6. Output Connector functions

Connector	Function
J2	RS232 Serial Output, normally NCOM
J4	RS232 Serial Output, normally NCOM Optionally CAN bus output
J6	10T or 100T Ethernet

The standard serial output of the RT3000 is a proprietary binary format, referred to as NCOM, this is described in detail at the end of the manual. Oxford Technical Solutions offers C and C++ code that will interpret the packet. This can be used freely in user's programs to interpret the output of the RT3000. For those who wish to interpret the packet directly, the format is provided here.

It is also possible to have a standard NMEA output from the RT3000 to mimic the output of GPS standard receivers.

Oxford Technical Solutions offers a service to tailor the serial output format to the customer's specifications. Contact Oxford Technical Solutions for details of this service.

Co-ordinate Frame Conventions

The RT3000 uses a co-ordinate frame that is popular with most navigation systems. Figure 3, below, shows how the axes relate to the RT3000 box.

Figure 3. RT3000 Co-ordinate Frame Definition

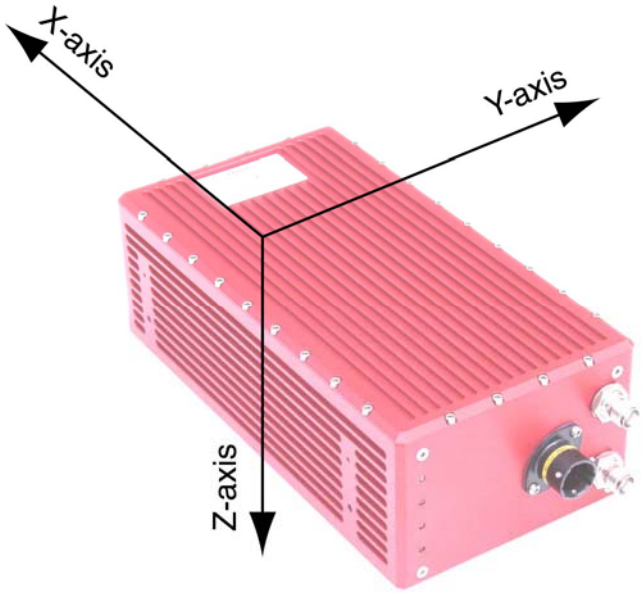


Table 7, below, lists the directions that the axes should point for zero heading, pitch and roll outputs when the default mounting orientation is used.

Table 7. Direction of Axes for zero Heading, Pitch and Roll outputs

Axis	Direction	Vehicle Axis
X	North	Forward
Y	East	Right
Z	Down	Down

If the axes of the RT3000 and the Vehicle Axes are not the same as those listed in Table 7, above, then they can be aligned by reconfiguring the RT3000 for a different mounting orientation. See section, Using OmniStar corrections, below.

LED Definitions

The front panel of the RT3000 has four LEDs. These give an indication of the internal state of the system. They can also be used for some simple operational checks on the system. The definitions of the LEDs are given in Table 8, below.

Table 8. LED Descriptions

LED	Position	Description
1	Top	Strapdown Navigator State
2	Top-Middle	Single Antenna: Position Solution Dual Antenna: GPS Heading Solution
3	Bottom-Middle	OEM4 GPS: Self-test
4	Bottom	Power/Comms

Strapdown Navigator LED States

The Strapdown Navigator LED shows the state of the Strapdown Navigator in the system. Table 9, below, gives the states of this LED.

Table 9. Strapdown Navigator LED States

Colour	Description
Off	The operating system has not yet booted and the program is not yet running. This occurs at start-up.
Red Flash	The operating system has booted and the program is running. The GPS receiver has not yet output a valid time, position and velocity.
Red	The GPS receiver has locked on to satellites and has adjusted its clock to valid time (the 1PPS output will now be valid). The Strapdown Navigator is ready to initialise. If the vehicle is travelling faster than 5 m/s then the Strapdown Navigator will initialise and the system will become active. On dual-antenna systems the system will initialise once the GPS receiver has determined heading, even if the vehicle is stationary or moving slowly.
Yellow	The Strapdown Navigator has initialised and data is being output, but the system is not real-time yet. It takes 10 seconds for the system to become real-time after start up.
Green	The Strapdown Navigator is running and the system is real-time.

In current versions of the software the Strapdown Navigator will not leave Green and return to any other state. This may change in future releases.

Position Solution (Single Antenna only)

The Position Solution LED shows what type of GPS solution is currently being used by the Kalman filter to update the Strapdown Navigator. Table 10, below, gives the states of this LED.

Table 10. Position Solution LED States

Colour	Description
Off	The GPS receiver does not have a valid position.
Red Flash	(Start-up only). The GPS receiver is sending data to the main processor. This is an operational check for the GPS receiver.
Red	The GPS receiver has a standard position solution (SA) or a differential solution (DGPS).
Yellow	The GPS receiver has a kinematic floating position solution (20cm accuracy).
Green	The GPS receiver has a kinematic integer position solution (2cm accuracy).

GPS Heading Solution (Dual Antenna only)

The GPS Heading Solution LED indicates the state of the dual antenna receiver. Table 11, below, defines the states of this LED.

Table 11. States of the GPS Attitude LED

Colour	Description
Off	GPS receiver fault. (Valid only after start-up).
Red Flicker	GPS receiver is active, but has been unable to determine heading.
Red	Integer uncalibrated heading lock.
Yellow	The receiver has a floating (poor) calibrated heading lock.
Green	The receiver has an integer (good) calibrated heading lock.

Self-Test LED

The Self-Test LED gives Novatel information about a failed GPS card. During normal operation this LED will flash Green.

Power/Comms LED

The Power/Comms LED shows the state of the internal 5V power-supply and the state of the TX line of the J2 connector. Table 12, below, gives the states of this LED.

Table 12. Power/Comms LED States

Colour	Description
Off	There is no power to the system or the system power-supply has failed.
Green	The 5V power supply for the system is active.
Orange	The system is outputting data on connector J2.

Fitting the Secondary Antenna

For best performance of the dual-antenna systems it is necessary to fit the secondary antenna to the system. The system is *very* sensitive to incorrect fitting and operation of the secondary antenna and these instructions should be followed carefully otherwise it is unlikely that the system will operate correctly.

Before fitting the secondary antenna bear the following information in mind:

1. In the default configuration the primary antenna should be at the front of the vehicle's roof and the secondary antenna should be at the rear.

2. The antenna separation must be correct to 3mm or better.

3. It is essential to orientate the antennas the same way. Always have the cable exiting from each antenna in the same direction. See Figure 4, below.

Figure 4. Dual-Antenna Orientations

4. For good multipath rejection the antennas must be mounted on a metal surface using the magnetic mounts provided; no additional gap may be used. Multipath affects stationary vehicle more than moving vehicles and it can lead to heading errors of 0.5 degrees RMS if the antennas are mounted poorly on the vehicle.

5. For both single antenna systems and dual antenna systems it is essential that the supplied GPS antenna cables are used and not extended, shortened or replaced. This is even more critical for dual antenna systems and the two antenna cables must be of the same specification. Do not, for example, use a 5m antenna cable for one antenna and a 15m-antenna cable for the other. Do not extend the cable, even using special GPS signal repeaters that are designed to accurately repeat the GPS signal. Cable length options are available in 5m, 15m and 30m lengths.

6. Mount both antennas where they have a clear, unobstructed view of the whole sky from all angles.

7. It is critical to have the RT3000 mounted securely in the vehicle. If the angle of the RT3000 can change relative to the vehicle then the dual-antenna system will not work correctly. This is far more critical for dual-antenna systems than for single antenna systems. The user should aim to have no more than 0.05 degrees of mounting angle change throughout the testing. (If the RT3000 is shock

mounted then the RT3000 mounting will change by more than 0.05 degrees; this is acceptable, but the hystersis of the mounting may not exceed 0.05 degrees).

When shipped the antenna separation is set to 1000mm exactly. It is possible to change the antenna separation distance, either for ease of use or to change the performance (a larger distance will improve performance). Contact Oxford Technical Solutions for details on how to change the antenna separation.

How the RT3000 uses the Dual-Antenna Measurements

It is often useful to have an understanding of how the RT3000 uses the measurements from the Dual-Antenna system. This can lead to improvements in the results obtained.

1. To use the measurements properly the RT3000 needs to know the angle of the GPS antennas compared to the angle of the RT3000. This cannot be measured accurately by users without very specialised equipment; the RT3000 needs to measure this itself as part of the warm-up process.

2. The RT3000 will lock on to satellites, but it cannot estimate heading so it cannot start. (In marine systems can start to perform a static search but this is not used in cars).

3. The vehicle drives forward, at about 12mph (or Initialization Speed) the RT3000 assumes that the Heading and Track are similar and initializes Heading to Track angle.

   If the RT3000 is mounted in the vehicle with a large heading offset then the initial value of heading will be incorrect. This can also happen if the RT3000 is initialised in a turn. This can lead to problems later.

4. When the combined accuracy of heading plus the Orientation Accuracy figure for the Secondary Antenna (see configuration software) is sufficiently accurate then the RT3000 will solve the RTK Integer problem using the Inertial heading. There is no need for the RT3000 to solve the RTK Integer problem by searching.

   If the antennas are offset from the RT3000 by a lot then the RTK Integer solution that is solved will be incorrect. It is essential to get the RT3000 orientation and the Secondary Antenna orientation to within 5 degrees.

5. Once the RTK Integer solution is available, the RT3000 can start to use the Dual-Antenna solution to improve heading. The level of correction that can be applied depends on how accurately the angle of the Secondary GPS Antenna is known compared to the Inertial sensors.

6. The Kalman filter tries to estimate the angle between the Inertial sensors and the Secondary GPS Antenna. The default value used in the configuration software (5 degrees) is not accurate enough so that the RT3000 can improve the heading

using this value. If you want the vehicle heading to 0.1 degrees, but you only know the angle of the two GPS antennas to 5 degrees, then the measurements from the antenna are not going to be able to improve the heading of the car.

Driving a normal warm-up, with stops, starts and turns, helps the Kalman filter improve the accuracy of the Secondary GPS Antenna angle. The accuracy of this angle is available in the Status information.

7. In the unlikely event that the RTK Integer solution is incorrect at the start then the Kalman filter can update the Secondary Antenna Orientation incorrectly. If this happens then things start to go wrong. The Kalman filter becomes more convinced that it is correct, so it resolves faster, but it always solves incorrectly. Solving incorrectly makes the situation worse.

   To avoid the Kalman filter from getting things wrong it is possible to drive a calibration run, then use the *Get Settings…* option of the configuration software. This will tell the Kalman filter that it has already estimated the angle of the Secondary Antenna in the past and it will be much less likely to get it wrong or change it. This step can only be done if the RT3000 is permanently mounted in a vehicle and the antennas are bolted on. Any movement of either the RT3000 or the antennas will upset the algorithms.

Multipath Effects on Dual-Antenna Systems

Dual-antenna systems are *very* susceptible to the errors caused by multipath. This can be from buildings, trees, roof-bars, etc. Multipath is where the signal from the satellite has a direct path and one or more reflected paths. Because the reflected paths are not the same length as the direct path, the GPS receiver cannot track the satellite signal as accurately.

The dual-antenna system in the RT3000 works by comparing the carrier-phase measurements at the two antennas. This tells the system the relative distance between the two antennas and which way they are pointing (the heading). For the heading to be accurate the GPS receivers must measure the relative position to about 3mm. The level of accuracy can only be achieved if there is little or no multipath.

In an ideal environment, with no surrounding building, trees, road signs or other reflective surfaces, the only multipath received is from the vehicle's roof. The antennas supplied with the RT3000 are designed to minimise multipath from the vehicle's roof when the roof is made of metal. For use on non-metallic roofs a different type of antenna is required (for example, the GPS-600 supplied with the base-station). This type of antenna can be supplied as an option.

When stationary the heading from the RT3000 will show some drift, the size of the drift depends on the multipath in the environment. Table 13, below, lists the drift you can expect when stationary with a 1m base-line.

Table 13. Typical Heading Drift for when Stationary in different Environments

Environment	Typical Drift
Complete Open-Sky	0.6 degrees max (0.2 degrees 1σ)
Near Trees, Buildings	1 degrees
Next to Trees, Buildings	2 degrees

Typical figures using a 1m base-line. For accuracy specification of 0.1 degrees RMS a 2m separation is required.

Setting-up the Base Station

For correct operation of the higher accuracy systems it is necessary to use a base-station GPS receiver. Refer to Table 1, above, to see if the system includes a base-station. All of the systems can be successfully used without a base-station, however, the specification will only be met if a base-station is used.

The base-station is a separate GPS receiver that monitors the signals from the GPS satellites. Using its knowledge of position it works out the errors in each satellite's signal. It also measures the carrier-phase of the signal for kinematic corrections. The carrier-phase observations and the satellite signal errors are sent from the base-station GPS to the RT3000 via a radio modem (not provided).

The position of the base-station GPS antenna can either be determined by the base-station GPS receiver or can be surveyed in by a chartered surveyor. If the base-station GPS receiver determines its own position, through position averaging, then any error in the base-station receiver will also result in error at the RT3000. In order to relate the RT3000 signals to maps, or other items on the world, it is necessary to have a surveyor measure the position of the GPS antenna and then tell the base-station GPS receiver what position to use.

For many applications it is not necessary to survey in the base-station antenna since an absolute world-reference is not required. Instead, a local grid can be used.

Using the RT-Base

The RT-Base system is a self-contained GPS, Radio Modem and Battery all in an IP65-rated 'Peli' case. For instructions on how to use the RT-Base see the RT-Base User Guide.

The RT-Base is supplied with a SATEL radio modem. This should be connected to the Radio connector of the RT3000 User Cable supplied (normally 14C0021A). This cable supplies power to the Radio Modem as well as sending the differential corrections to the RT3000.

Using the Novatel Power-Pak

For base-stations supplied as a Novatel Power-Pak (now superseded by the RT-Base) the following instructions apply.

You are advised to look at the Novatel Millennium GPSCard *Command Descriptions Manual* for more details on how the base-station operates. The manual includes a lot of information on base-stations and covers the topic in more detail than is described here.

Recently the type of base-station supplied has changed. The new base-station receivers use an OEM4 GPS card from Novatel, whereas the original ones use an OEM3 card. Please follow the instructions specific to your card where marked in the text.

To set up a base-station the following steps must be followed.

1. Place the base-station GPS receiver at a suitable location. The receiver should be inside in a dry environment and it will require a 12V (9-36V) d.c. power supply.

2. Place the GPS antenna where it has a clear view of the whole sky. It is very important for the base-station GPS to have full view of the whole sky; any satellite it cannot receive cannot be used by the RT3000, even if the RT3000 can see the satellite. It is also important to place the GPS antenna in a low multipath environment.

3. Connect the GPS antenna to the base-station GPS receiver using the GPS antenna cable provided.

4. Connect COM1 of the base-station GPS receiver to a laptop computer

5. Run Novatel's GPSoln32 (OEM3 model) software or GPSolution4 (OEM4). (This software is included on the RT3000 Software CD in the OEM3/OEM4 directory. It will need to be installed on the computer.)

6. Open a connection to the GPS receiver. Any baud rate can be used as the software will search for the correct baud rate. Open a Command Console window and an ASCII Logs window. The best baud rate to use for connecting to the base-station is the default, 9600.

7. If the base-station GPS receiver is determining its own position use the `POSAVE` command to average the position and then store it. For example, to average the position for 0.1 hours (6 minutes) type:

   `POSAVE 0.1`↵ (OEM3 or OEM4 receiver)

   If the base-station antenna position is known then use the `FIX POSITION` command to enter the exact position of the antenna. For example, to fix the position of the GPS antenna at 51.3455323 degrees north latitude, 114.289534 degrees west longitude and 1201.123 metres above the geoid reference type:

   `POS FIX 51.3455323 -114.289534 1201.123`↵ (OEM3)

   `FIX POSITION 51.3455323 -114.289534 1201.123`↵ (OEM4)

   Refer to the Novatel Millennium GPS Card *Commands Description Manual* for more details on these commands.

8. Once the base-station has fixed its position, this position can be saved to non-volatile memory and used automatically next time the GPS receiver is turned on. To do this type:

   ```
   SAVECONFIG↵
   ```

9. While the base-station is averaging its position connect COM2 of the base-station GPS to the radio modems. The communications settings of the radio modem will have to match the communication settings of the GPS receiver, listed below.

Note: If the base-station antenna is moved then it is necessary to re-average the position or to re-enter the new surveyed co-ordinates. Once the base-station has had its position fixed the valid position light will be on, even when there are no valid satellites (i.e. at start-up before it has correctly acquired the satellites and before it is transmitting valid corrections).

Using OmniStar corrections

RT3000 products that have OmniStar decoders in them can be used to get corrections from OmniStar satellites. The RT3000 family members support both OmniStar VBS (giving 50cm CEP) and OmniStar HP (giving 10cm CEP in extended periods of open sky).

Before OmniStar corrections can be used it is essential to get a license from OmniStar. To get a license the following must be done:

1. The configuration software needs to be used to set the satellite that the RT3000 will use to get corrections. There are only a few satellites available, so this is not something that needs to be changed often.

2. Set up the RT3000 outside and turn it on. Make sure that it has a good view of the open sky. Check that the RT3000 is tracking the OmniStar satellite, this can be found in the Status information. For an HP license it can take 45 minutes of continuous tracking to get the full information for HP corrections.

3. Call OmniStar are ask them to activate the OmniStar receiver. They will need the serial number of the OmniStar card in the RT3000. This is given on the delivery note of the RT3000.

4. After the license has been sent, the RT3000 will operate in VBS mode. If an HP license has been sent then it may take 45 minutes before HP will start to work; an almanac transmission is required, and this is only sent slowly. Any break in the OmniStar transmission will mean that the almanac cannot be received.

After OmniStar is configured and a valid license is obtained, the RT3000 will automatically use OmniStar whenever it is available. The availability of the OmniStar signal can be monitored using the Status Information.

Changing the RT3000's Configuration

The default parameters that the RT3000 is shipped with will work for most applications. To get the best results from your RT3000 it is necessary to change the configuration to suit the way you have installed the RT3000 in your vehicle.

The program `RT3000Cfg.EXE` can be used to do this. This section describes how to use `RT3000Cfg` and gives additional explanations on the meanings of some of the terms used.

It is only possible to change the RT3000's configuration using Ethernet. It is necessary to have the Ethernet on your computer configured correctly in order to communicate with the RT3000 and change the settings.

Overview

In order to give the best possible performance, the RT3000 needs to know the following things:

- The orientation that the RT3000 is mounted at in the vehicle
- The position of the Primary GPS antenna compared to the RT3000
- The orientation of the Dual-antennas compared to the RT3000
- Position of the Rear-Wheels (or non-steering wheels) compared to the RT3000
- Some environment parameters

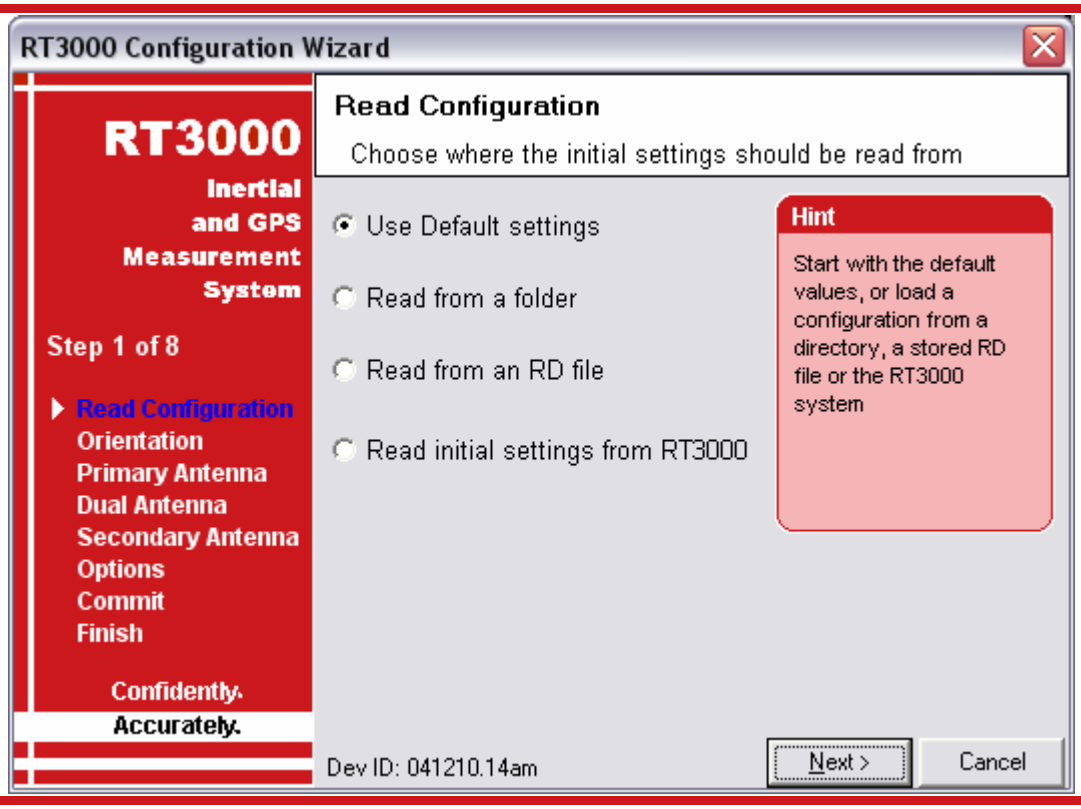
Many of these parameters the RT3000 can figure out by itself, but this takes time. Measuring the parameters yourself and configuring the RT3000 shortens the time before full specification can be met.

If the RT3000 has been running for some time, it will have improved the measurements that you have made. It is possible to read these improved measurements into `RT3000Cfg`, commit them to the RT3000 and then use them next time you start the system. If you move the RT3000 from one vehicle to another it is essential that you return to the default configuration rather than using a set of parameters that have been *tuned* for a different vehicle.

Reading the Initial Configuration

The first page of `RT3000Cfg` gives several options for reading the configuration from different places. Figure 5, below, shows `RT3000Cfg` just after it is started.

Figure 5. `RT3000Cfg` Initial Screen



Default Settings. To use the default settings select this radio button. The following pages will contain the default settings that the RT3000 was delivered with.

Read from a Folder. It is possible to store a configuration in a folder. The configuration requires several files so it is tidier to keep it in a folder by itself. To read the configuration from a folder select this radio button. A group box will appear and the folder can be selected.

Read from an RD File. The RT3000 writes the configuration it is using to the internally stored RD file. This option extracts the configuration used at run time.

Read Initial Settings from RT3000. If the RT3000 is connected to the computer via Ethernet then it is possible to read the initial settings directly from the RT3000. The initial settings are the settings that the RT3000 starts up with, before it makes any improvements. Select this radio button and enter the correct IP address of your RT3000.

Orientation of the RT3000 in the vehicle

The RT3000 can be mounted at any angle in the vehicle. The outputs can be rotated so that the measurements can be referenced to the vehicle co-ordinate frame. For correct initialisation it is also necessary to get the heading orientation correct. If the 'vehicle level' option is used then the pitch and roll orientations must also be correct.

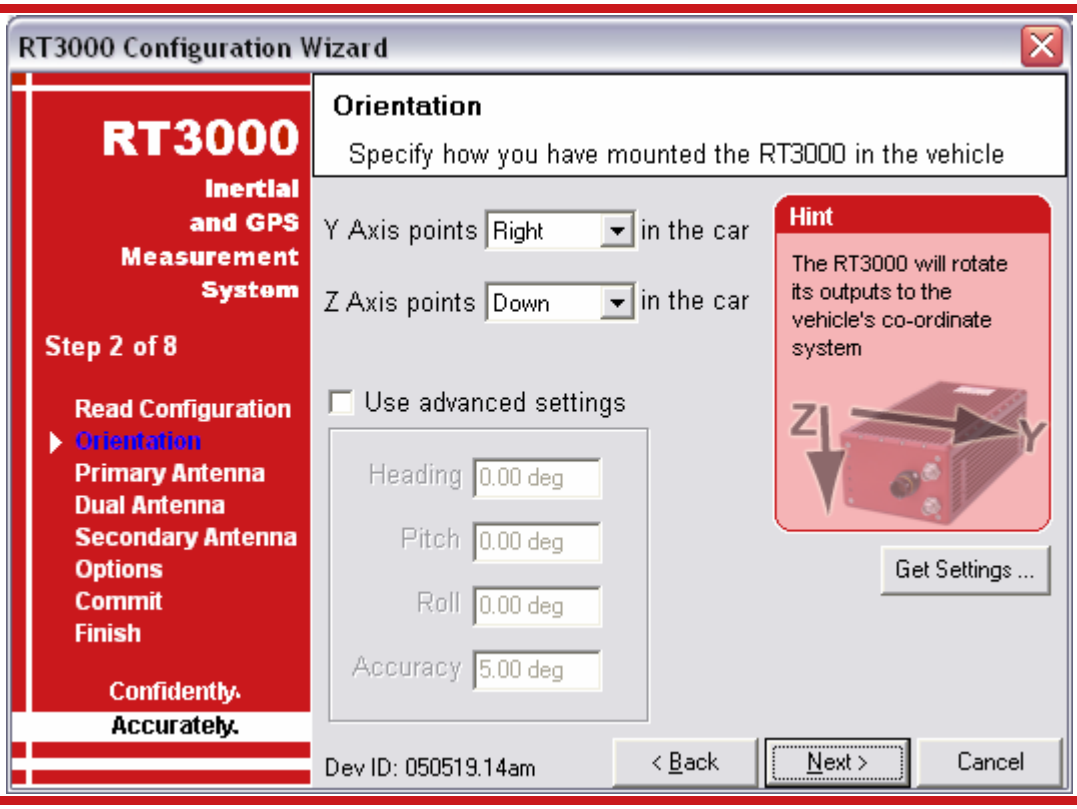
The RT3000 gets its initial heading by assuming that the lateral velocity or slip angle is small. If the definition of the vehicle's X-axis (forward direction) is incorrect in the RT3000 then it will not initialise correctly when the vehicle drives forwards.

The orientation of the RT3000 in the vehicle is normally specified using three consecutive rotations that rotate the RT3000 to the vehicle's co-ordinate frame. The order of the rotations is Heading (Z-axis rotation), then Pitch (Y-axis rotation), then Roll (X-axis rotation). The RT3000 co-ordinate conventions are listed in Figure 3, above and Table 7, above. Take care to get the order of the rotations correct.

When using the Oxford Technical Solutions RT-Strut the orientation will need to be changed. The RT-Strut has the Y-axis pointing right and the Z-axis pointing backwards.

Figure 6, below, shows the orientation screen of `RT3000Cfg`.

Figure 6. `RT3000Cfg` Orientation Screen



To work out the direction that the RT3000 is mounted at look to see which directions the Y-axis and the Z-axis are pointing. Then enter these directions in to the software. The greyed out Advanced Settings will change to show the three rotations associated with orientation chosen.

To make small adjustments use the advanced settings. This allows the user to 'zero' any slip angle offsets, pitch offsets or roll offsets.

When using Advanced Slip, the RT3000 can estimate the Slip Angle offset of the RT3000 compared to the car. Once the RT3000 is initialised and warmed-up select the *Get Settings…* button. This will read the RT3000's estimate of Slip Angle offset automatically and ensure that a slip angle of zero is measured when driving straight on a level track.

More information on the *Get Settings…* option is provided later on in the manual.

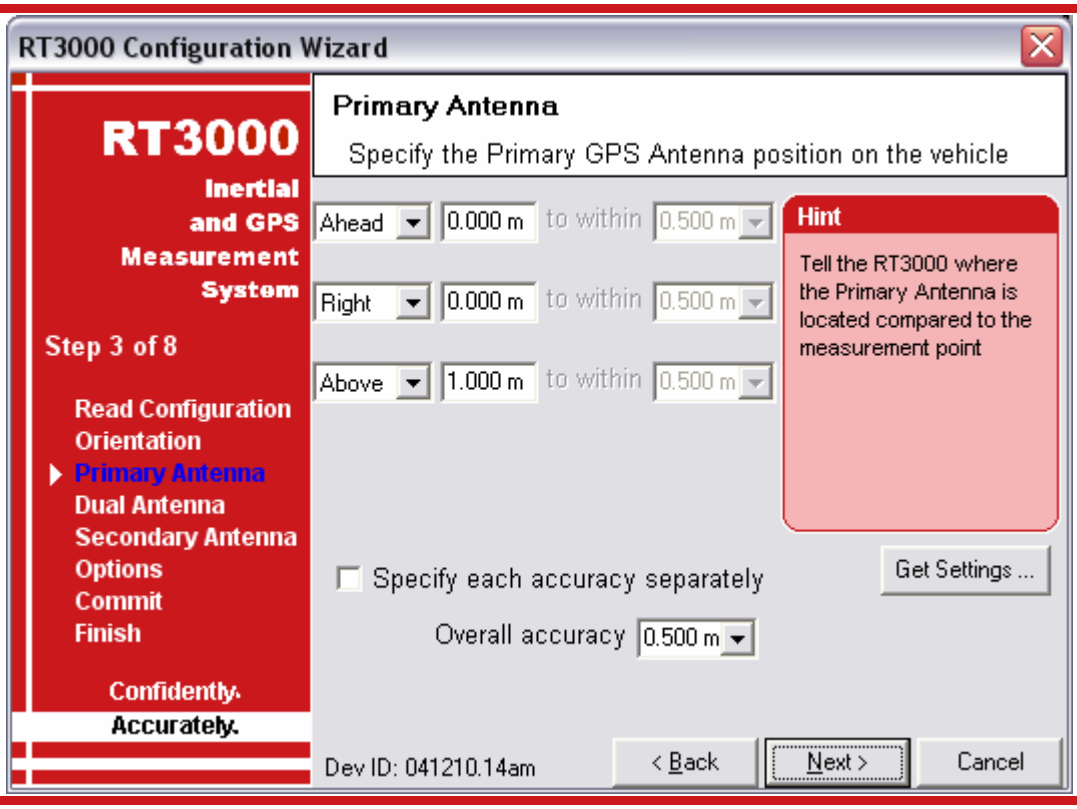
Specifying the Position of the Primary Antenna

The RT3000 is able to measure the position of the Primary Antenna itself. However, this takes time and better results can be achieved sooner if the user measures the distance accurately. Getting these measurements incorrect is one of the main reasons for poor results from the RT3000, so it is important to be careful with the measurements.

The RT3000 is much better at measuring the position of the GPS antenna in 2cm mode compared with 1.8m mode. In 2cm mode the antenna position can be estimated after a few circles, whereas in 1.8m mode it can take several hours. When using the RT3000 in 1.8m mode it is recommended to measure the GPS antenna position accurately.

Figure 7, below, shows the Primary Antenna screen.

Figure 7. `RT3000Cfg` Primary Antenna Screen



It is necessary to tell the RT3000 the distance from the measurement point (shown on diagram 14A0007*x* at the end of this manual) to the GPS antenna measurement point. This should be entered in the vehicle's co-ordinate frame (note that the software deliberately uses a left-handed co-ordinate frame here because it is conceptually easier).

The accuracy of the measurements should also be specified. Care should be taken here because it is very easy to measure distance to 1cm or better in a straight line. It is much harder to measure to 1cm through a car roof and it is much harder to measure to 1cm if the RT3000 is slightly misaligned in the vehicle. Any alignment errors should be included in the accuracy that you believe you can measure to.

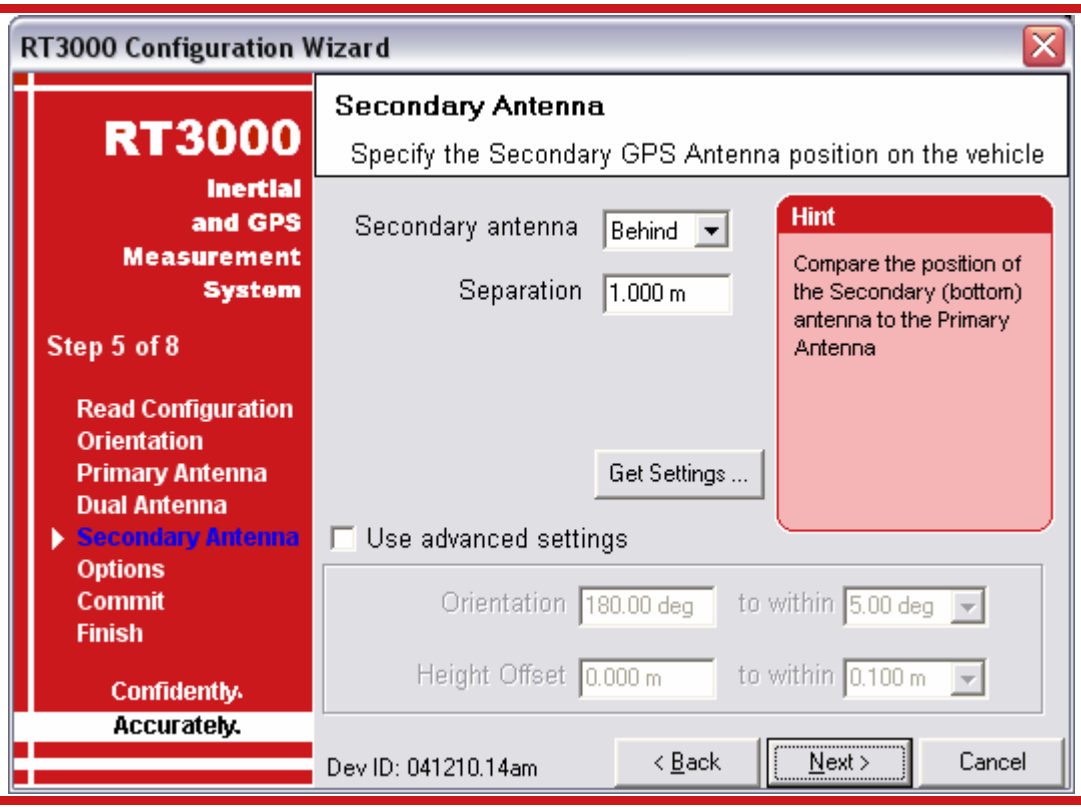
Telling the RT3000 that you have measured the distances to 1mm may lead the RT3000 to believe its results are better than they really are. You may be impressed by the accuracy that the RT3000 reports, but in reality it will not be that accurate. It is better to overestimate the accuracy than to underestimate it.

The RT3000 will try to improve the position of the Primary GPS Antenna. To use the values that the RT3000 has estimated select the *Get Settings*... option. More information on the *Get Settings*... option is provided later on in the manual.

Specifying the Orientation of the Secondary Antenna

If your system has two antennas then it is necessary to tell the RT3000 the orientation of the two-antenna system compared to the vehicle. It is critical to tell the RT3000 the exact distance between the two antennas (to 5mm or better).

Figure 8. `RT3000Cfg` Secondary Antenna Screen



It is best to mount the two antennas on the top of the vehicle. Although it is possible to mount one on the roof and one of the bonnet (hood), in reality the multi-path reflections from the windscreen will degrade the performance of the system.

If the antennas are mounted at significantly different heights or if the mounting angle is not directly along a car axis (forward or right) then use the advanced settings.

Getting the angle wrong by more than 3 degrees can lead the RT3000 to lock on to the wrong heading solution. The performance will degrade or be erratic if this happens.

The RT3000 does not estimate the distance between the two antennas. It is essential to get this right yourself, otherwise the system will not work correctly and the performance will be erratic. The measurement needs to be accurate to 5mm, preferably better than 3mm.

The RT3000 will improve the estimate of the Secondary Antenna settings. To use the values that the RT3000 has estimated click the *Get Settings*...button. More information on the *Get Settings*... option is provided later on in the manual. Before using this option for Dual-Antenna systems the following should be considered:

- If the antennas are mounted magnetically on the roof and someone moves the antenna then the values estimated by the RT3000 will be incorrect for the new antenna positions. This will lead to poor Slip Angle performance.

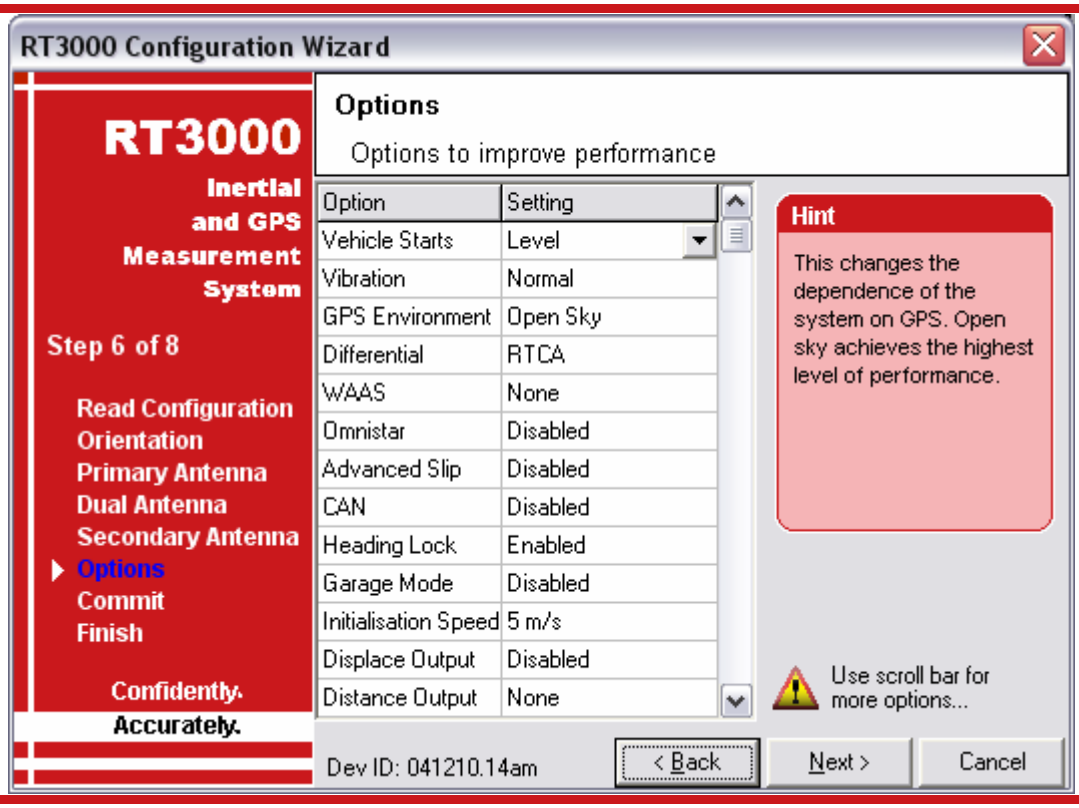
- If the RT3000 is not mounted very securely in the vehicle and someone knocks it and changes the mounting angle then the values estimated by the RT3000 will be incorrect for the new RT3000 mount angle. This will lead to poor Slip Angle performance.

For these reasons it is recommended to only use the *Get Settings*... option for Dual-Antenna systems when the RT3000 is permanently and securely mounted.

Setting the Correct Options

The Options Page includes some important settings for getting the best results from your RT3000 system. Figure 9, below, shows the Options screen.

Figure 9. `RT3000Cfg` Options Screen



Vehicle Starts Option

If you know that the vehicle will be level when starting (to within about 5 degrees) then the *Level* option can be used. This saves about 40 seconds during the initialisation process since the RT3000 does not have to take the time to compute an initial roll and an initial pitch. In high vibration environments the *Not Level* option may not work and so the RT3000 can only start if the vehicle is level and the *Level* option has been specified.

Vibration Option

The *Normal* vibration level is adequate for most circumstances. The RT3000 is very tolerant of vibration and has been used successfully in environments with more than 2g RMS using the Normal setting. If the velocity innovations are very high and many GPS packets are being dropped then this setting can be changed.

GPS Environment Option

If the system is used predominantly in open-sky then the *open-sky* setting should be used. In environments with a lot of GPS multi-path the other two settings can be used. This will allow less accurate GPS measurements to update the system.

Differential Correction Option

The RT3000 can be configured to use several different Differential correction message types on connector J3. The RT-Base transmits RTCA messages. RTCM (RTCM-104) or CMR (Trimble) can also be selected or the port can be disabled. The Advanced option should not be used except in specialised applications. The corrections are always received at 9600 baud.

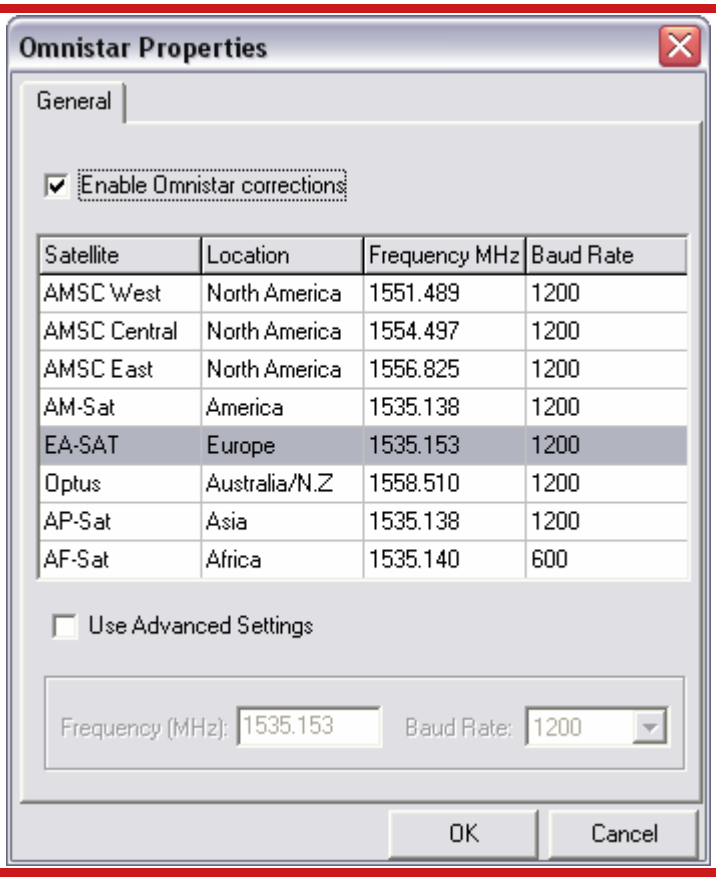
WAAS Option

For WAAS enabled systems the GPS receiver can be set up to receive corrections in North America or Europe. Because WAAS (North America) and EGNOS (Europe) are in test mode they can sometimes be unreliable; the corrections can be disabled by selecting *None*. For systems that do not have WAAS capability this setting has no effect and is ignored.

OmniStar Option

For OmniStar Enabled Systems the correct satellite should be selected for the region where you are operating. The correct satellite must be selected before OmniStar can send a new license. For systems that do not have OmniStar capability this setting has no effect and is ignored.

Figure 10. `RT3000Cfg` OmniStar Properties

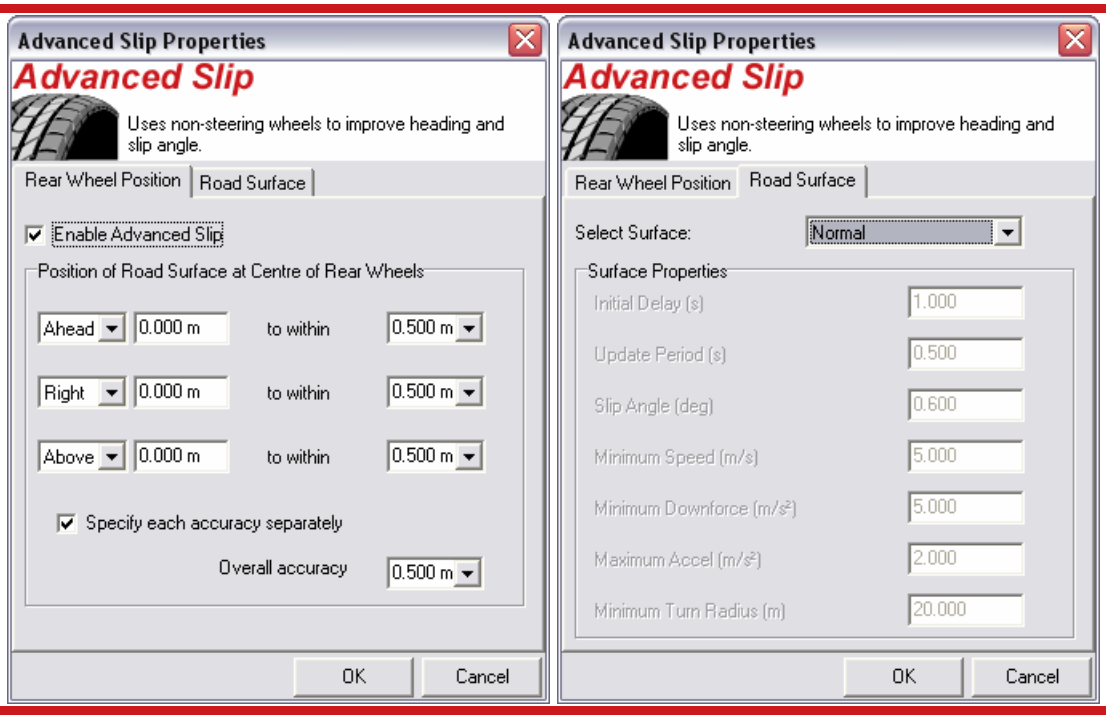


Several satellites have been pre-programmed into the software. In the future more satellites may exist, or their properties may change. In this case it is necessary to use the *Advanced Settings* to set the Satellite's Frequency and Baud Rate.

Advanced Slip Option

The Advanced Slip feature uses characteristics of land vehicle motion to improve heading and slip angle. This feature **must** be disabled for airborne and marine systems where the lateral velocity can be significant. The Advanced Slip feature applies heading correction when the land vehicle is not slipping; when the car is slipping the lateral acceleration is usually large enough so that the normal heading corrections provide excellent results.

Figure 11. `RT3000Cfg` Advanced Slip Properties



For the Advanced Slip feature to work correctly the system needs to know the position of the rear-wheels on a vehicle with front-wheel steering. (Vehicles with rear-wheel steering should use the front wheels; vehicles with all wheels steering cannot use this feature reliably). Minor steering of the rear-wheels does not significantly affect the results. A position at road height, mid-way between the rear wheels should be used.

The Advanced Slip feature also requires some knowledge of the road surface. Three pre-defined options are given, *Normal, Low Friction (Ice)* and *High Friction*. The *Other* feature should not be used.

CAN Option

The CAN bus can be disabled or the correct baud rate can be selected. In systems without the CAN option this should be set to *Disabled*.

Heading Lock Option

The heading of Single Antenna systems can drift when the RT3000 remains stationary for long periods of time. To solve this the RT3000 includes an option to lock the heading to a fixed value when stationary. This option cannot be used if the vehicle can turn on the spot (i.e. turn with zero speed).

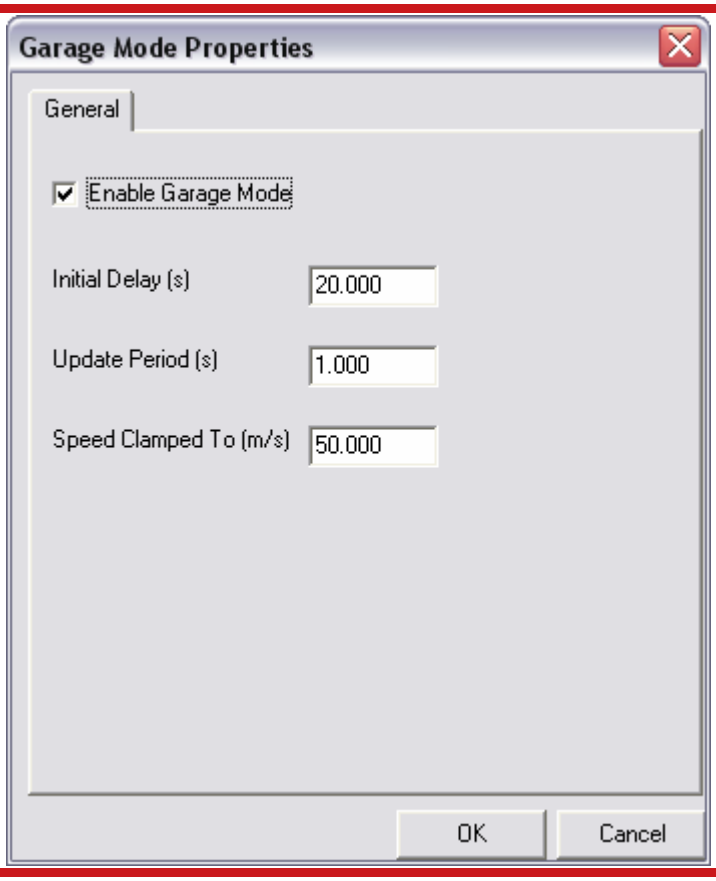
With Heading Lock enabled the RT3000 can remain stationary for indefinite periods of time without any problems. For vehicle testing this option is recommended.

Garage Mode Option

The Garage Mode option can be used to stabilise the RT3000 outputs when GPS is not available. For example, GPS can be blocked when the vehicle returns to the garage to have some modifications. Without Garage Mode the RT3000 may drift too far and may not be able to recover.

When Garage Mode is active, the RT3000 applies a gentle velocity update and assumes that the vehicle is stationary. This keeps the roll, pitch and velocity within acceptable limits while the RT3000 has no GPS. With Heading Lock also enabled, the RT3000 can also keep the heading accurate while stationary.

Figure 12. `RT3000Cfg` Garage Mode Properties



The default settings are usually sufficient for Garage Mode to operate successfully. However, if you are using the RT3000 in tunnels or in other environments where GPS is not available for long periods of time then it may be necessary to increase the *Initial Delay* setting.

The other two settings are mainly for research and should not be changed.

Initialisation Speed Option

The default starting speed for the RT3000 is 5m/s. However, some slow vehicles cannot achieve this speed. For these vehicles adjust the *Initialisation Speed* to a different value.

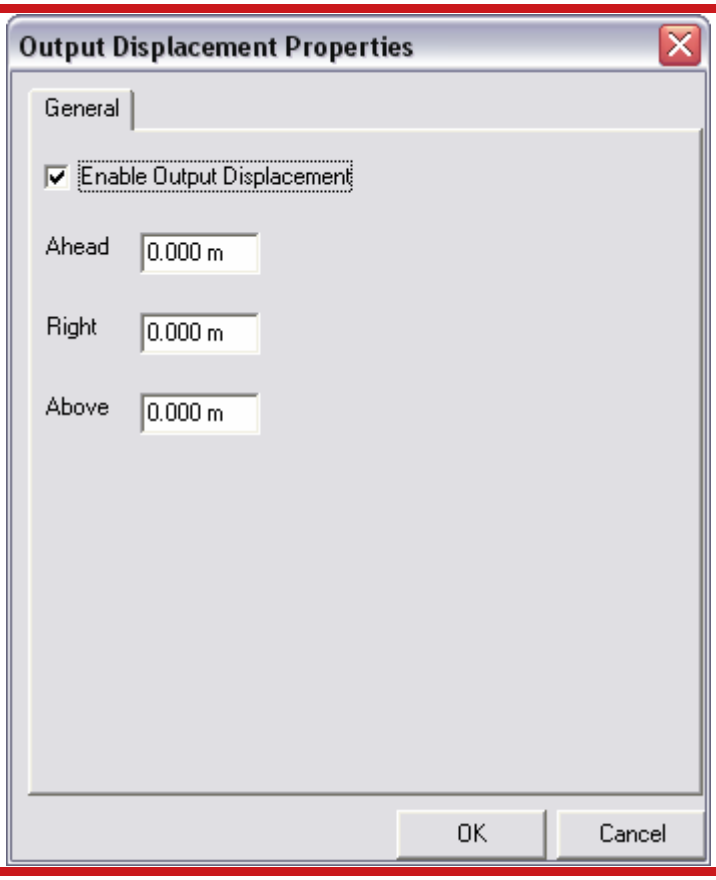
If a speed less than 5m/s is selected then care should be taken to make sure that the RT3000 is travelling straight when it initialises.

Displace Output Option

The RT3000 can displace or move its outputs to another location in the vehicle. This simulates the RT3000 being mounted at the new location, rather than at its actual location.

To enable Output Displacement select this option and enter the offsets to the new location in the vehicle.

Figure 13. `RT3000Cfg` Output Displacement Properties



Distance Output

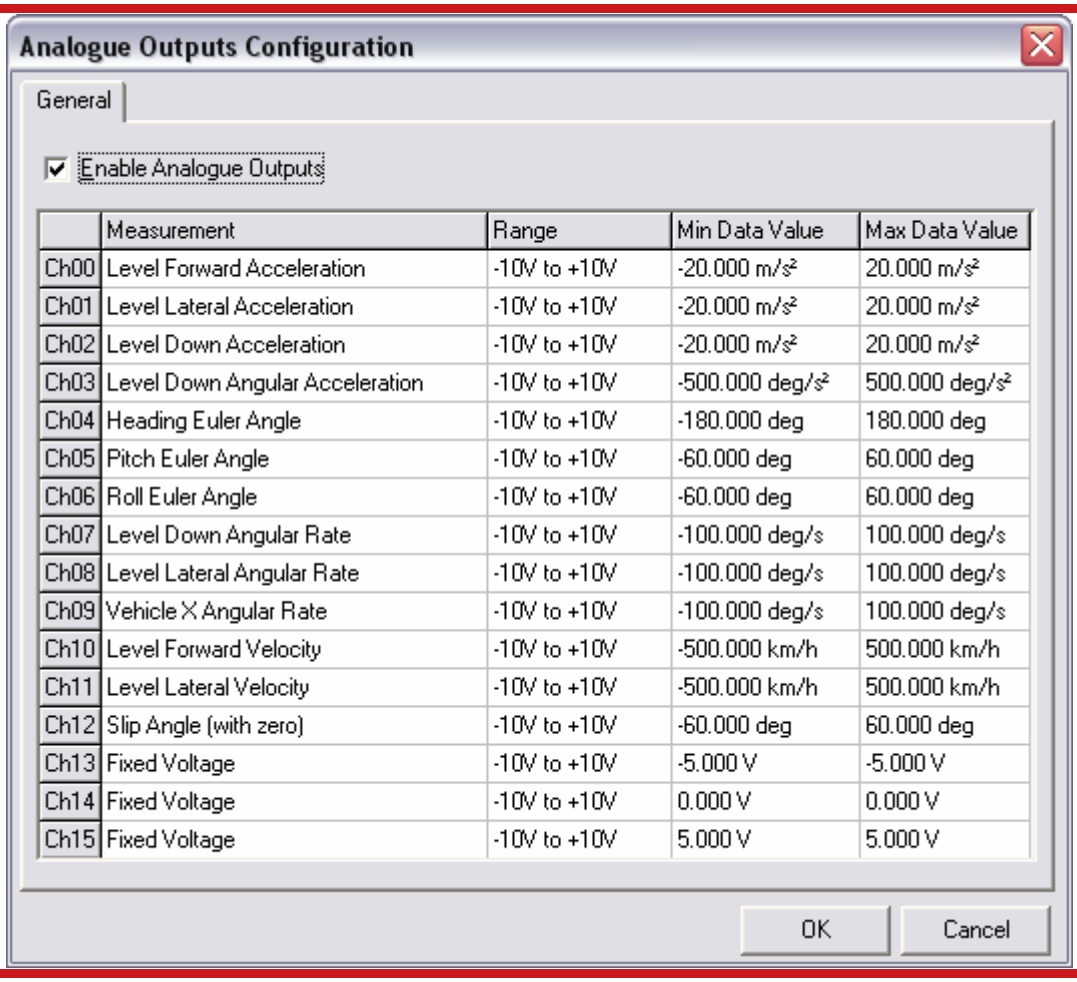
It is possible to have the RT3000 configured to simulate the output of a wheel encoder. This will be in the form of TTL pulses, each pulse representing a distance travelled. Using the Distance Output option the scaling of this output can be configured, in pulses per metre travelled.

Analogue Outputs

The configuration of the RT-ANA is done using the RT3000 Configuration Software. There are 16 channels in the RT-ANA, numbered from 0 to 15. The channel selection, range and scaling for all 16 channels can be configured. Double-click on a specific channel to change the settings.

Note: The CAN bus must be configured correctly for the Analogue Outputs to work correctly.

Figure 14. `RT3000Cfg` Analogue Outputs Configuration



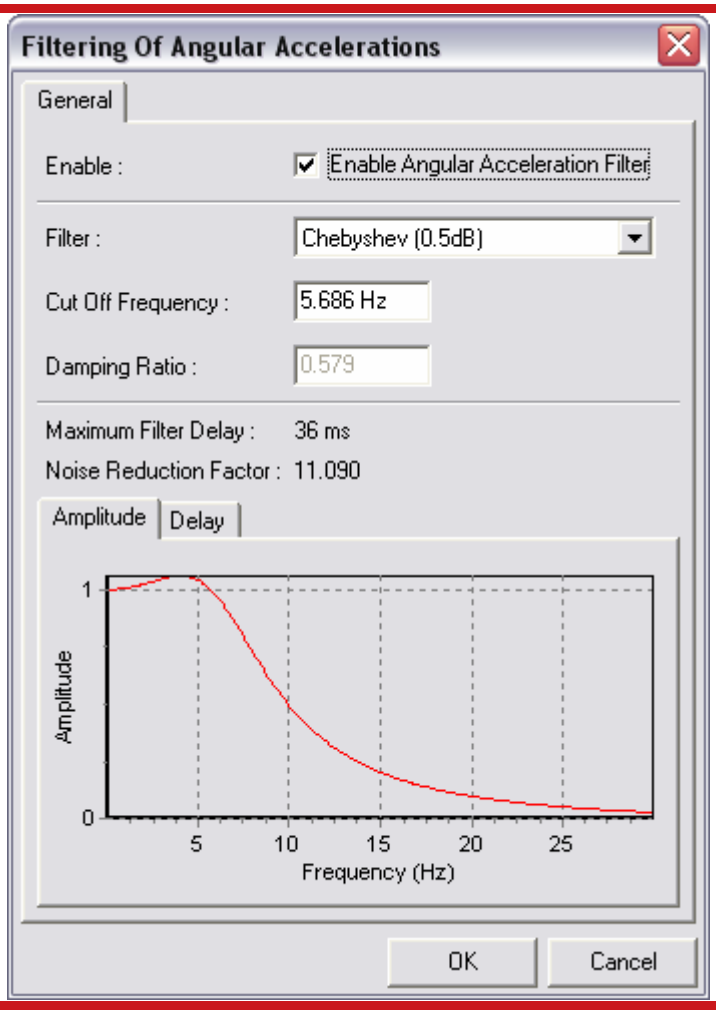
	Measurement	Range	Min Data Value	Max Data Value
Ch00	Level Forward Acceleration	-10V to +10V	-20.000 m/s²	20.000 m/s²
Ch01	Level Lateral Acceleration	-10V to +10V	-20.000 m/s²	20.000 m/s²
Ch02	Level Down Acceleration	-10V to +10V	-20.000 m/s²	20.000 m/s²
Ch03	Level Down Angular Acceleration	-10V to +10V	-500.000 deg/s²	500.000 deg/s²
Ch04	Heading Euler Angle	-10V to +10V	-180.000 deg	180.000 deg
Ch05	Pitch Euler Angle	-10V to +10V	-60.000 deg	60.000 deg
Ch06	Roll Euler Angle	-10V to +10V	-60.000 deg	60.000 deg
Ch07	Level Down Angular Rate	-10V to +10V	-100.000 deg/s	100.000 deg/s
Ch08	Level Lateral Angular Rate	-10V to +10V	-100.000 deg/s	100.000 deg/s
Ch09	Vehicle X Angular Rate	-10V to +10V	-100.000 deg/s	100.000 deg/s
Ch10	Level Forward Velocity	-10V to +10V	-500.000 km/h	500.000 km/h
Ch11	Level Lateral Velocity	-10V to +10V	-500.000 km/h	500.000 km/h
Ch12	Slip Angle (with zero)	-10V to +10V	-60.000 deg	60.000 deg
Ch13	Fixed Voltage	-10V to +10V	-5.000 V	-5.000 V
Ch14	Fixed Voltage	-10V to +10V	0.000 V	0.000 V
Ch15	Fixed Voltage	-10V to +10V	5.000 V	5.000 V

Angular Acceleration Filter (Ang Acc Filter)

Due to vibration angular acceleration is very noisy. When it is used it is normally filtered. The RT3000 can filter the Angular Acceleration outputs using a second order low-pass filter. The characteristics of the filter can be set and viewed in the Angular Acceleration Filter Option Page.

Designing the right filter is always a compromise between the noise reduction and the filter delay. To help choose the filter you require, the software will compute the maximum delay over the 0 to 5Hz interval and the Noise Reduction Factor over the full bandwidth. The Noise Reduction Factor is the ratio of the filtered noise compared to the unfiltered noise assuming that the vibration is white (i.e. same amplitude across the frequency spectrum). A graph showing the delay with respect to frequency can also be plotted. The delay is the *additional* delay of the filter and not the total delay of the angular acceleration output. The RT3000 has other delays, like calculation delay, too.

Figure 15. `RT3000Cfg` Angular Accelerations Filter Configuration



Wheel Speed Input

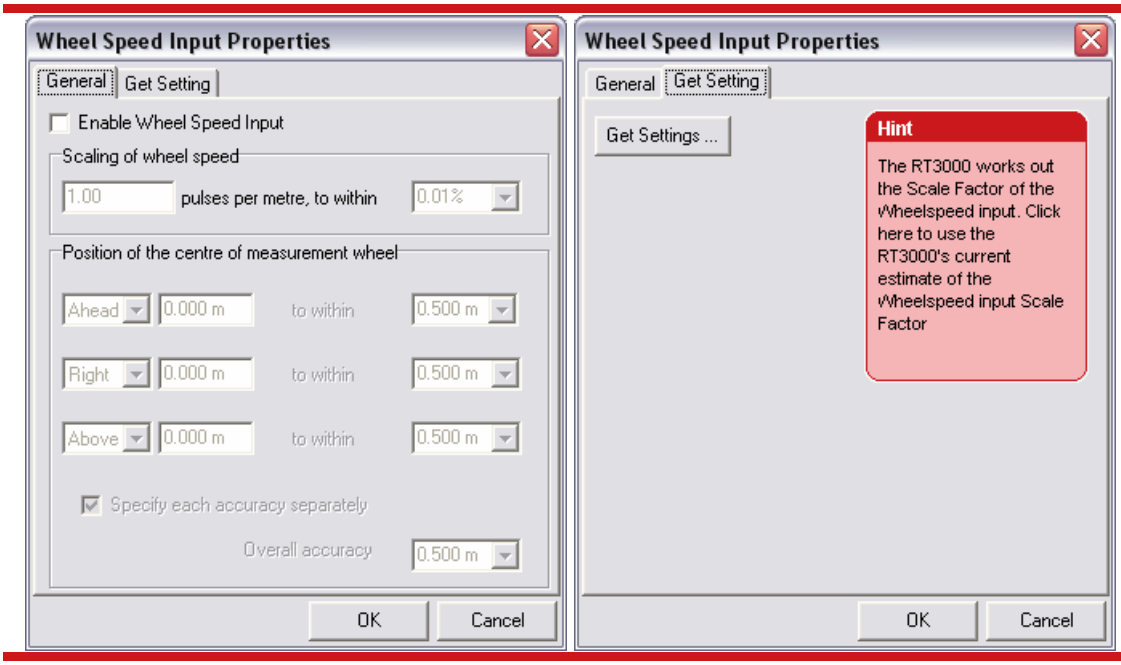
The RT3000 can be factory configured to include a Wheel Speed Input. This reduces the drift in the outputs when GPS is not available.

To use the Wheel Speed Input the RT3000 needs to be configured to know the number of pulses per metre that the wheel generates, the accuracy expected from the wheel gripping on the road surface and the vector from the RT3000 to the wheel centre. The RT3000 will improve the accuracy of the Wheel Speed Scaling when GPS is available.

The RT3000 will not work properly if the encoder is measuring two wheels (i.e. after a differential) since the actual position of the wheel is required for accurate navigation. If a post-differential encoder must be used then the accuracy cannot be guaranteed.

The RT3000 will improve the estimate of the Wheel Speed Scaling. To use the value that the RT3000 has estimated select *Get Settings…* on the *Get Setting* tab. If this option is used then the RT3000 should be allowed to recalibrate the scaling value occasionally to account for tyre wear. To do this return the *to within* value to 1% again and perform a calibration drive.

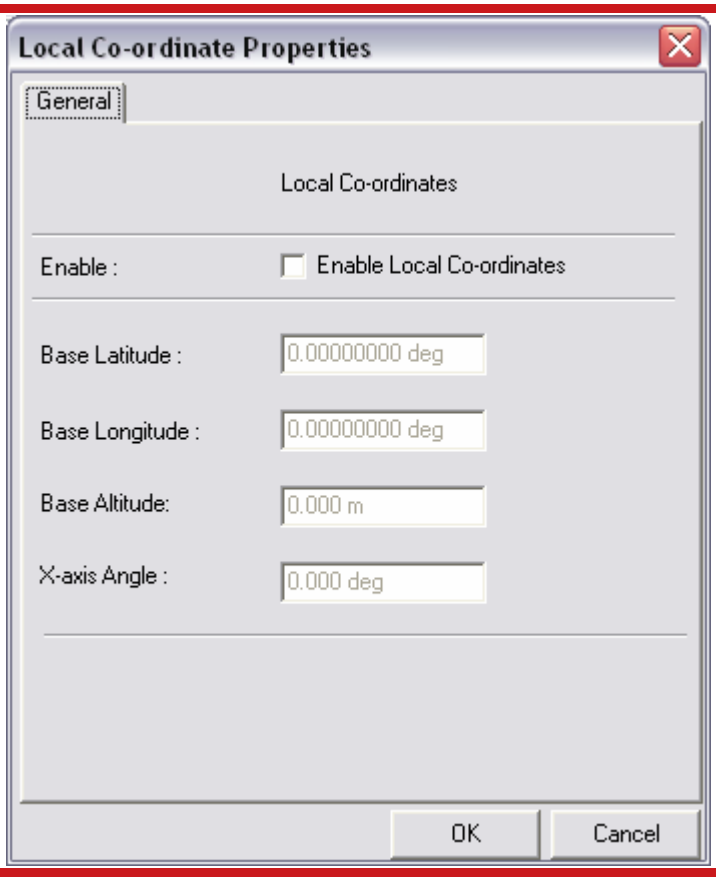
Figure 16. `RT3000Cfg` Wheel Speed Input Configuration



Local Co-ordinates

The RT3000 can output the displacement from an origin in a local co-ordinate grid. To use this option a “zero” location or origin must be chosen; the latitude, longitude and altitude for the origin must be entered in to the RT3000. If an RT-Base is available then these will be shown on the LCD display. A rotation can also be specified to rotate the XY directions.

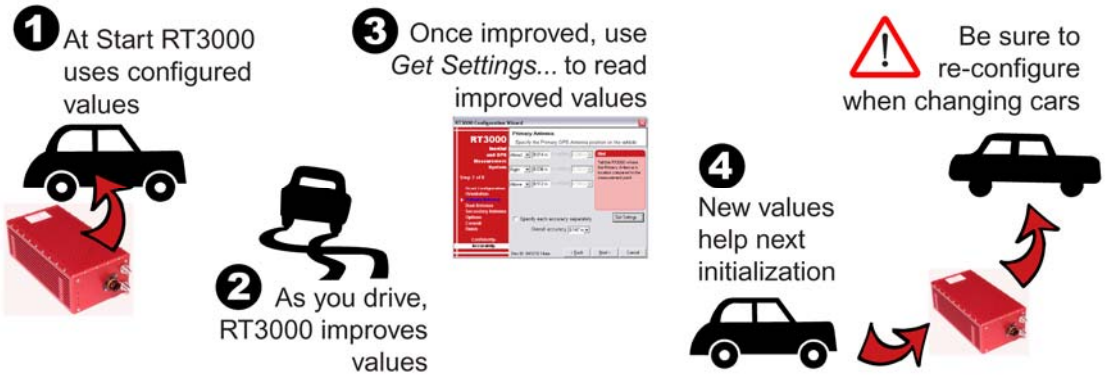
Figure 17. `RT3000Cfg` Local Co-ordinate Configuration



Get Settings…

The *Get Settings…* option, which appears on several pages of the RT3000 Configuration Software, should be used to read improvements that the RT3000 has made to the configuration parameters. This can be useful for making the measurements more consistent and for reducing the warm-up time.

Figure 18. Process of improving RT3000 Settings


1 At Start RT3000 uses configured values
2 As you drive, RT3000 improves values
3 Once improved, use Get Settings... to read improved values
4 New values help next initialization
Be sure to re-configure when changing cars

The settings can be read from three sources:

- from an NCOM file. If an NCOM file has been saved to disk, or processed using the post-process utility then this file can be read and the settings extracted from it. Use this setting if you have an NCOM file.

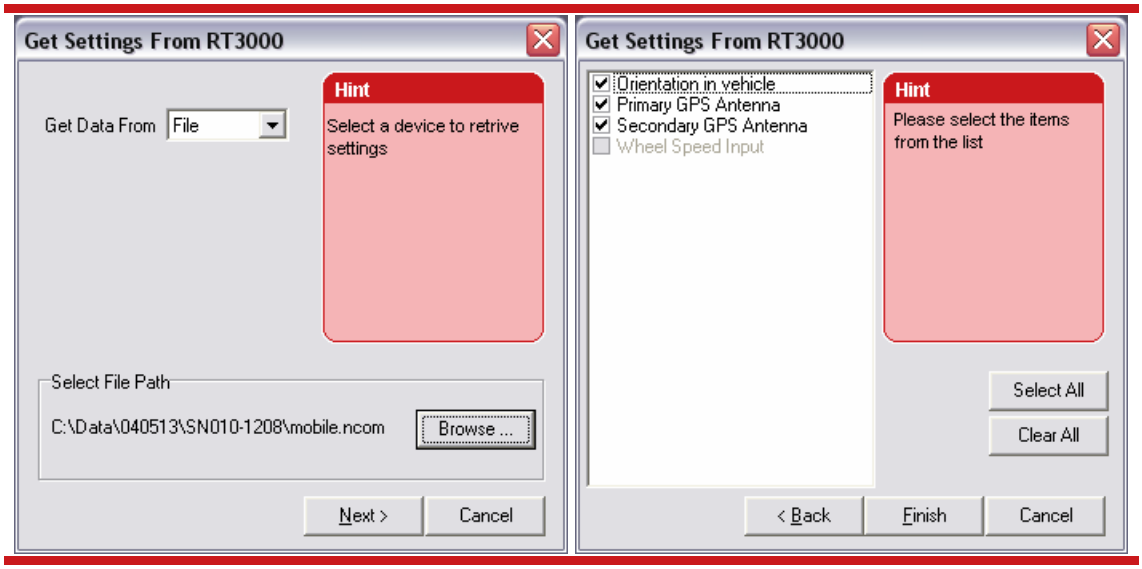
- from an RT3000 connected to the serial port. This will get the information that the RT3000 is using at the moment and apply it next time the RT3000 starts. Use this setting if the RT3000 is running, has initialised and has warmed up.

- from an RT3000 connected to the Ethernet port. This will get the information that the RT3000 is using at the moment and apply it next time the RT3000 starts. Use this setting if the RT3000 is running, has initialised and has warmed up.

Once the source has been selected the software will find which settings can be obtained from the source. Settings that cannot be obtained will be shown in grey; this may be because the RT3000 was not calculating these values at present.

You may update several parameters at once using the *Get Settings…* option. Select which settings you want to be updated and uncheck the ones that you do not want to update. When you press *Finish* these settings will be transferred to the wizard.

Figure 19. `RT3000Cfg` Get Settings Pages

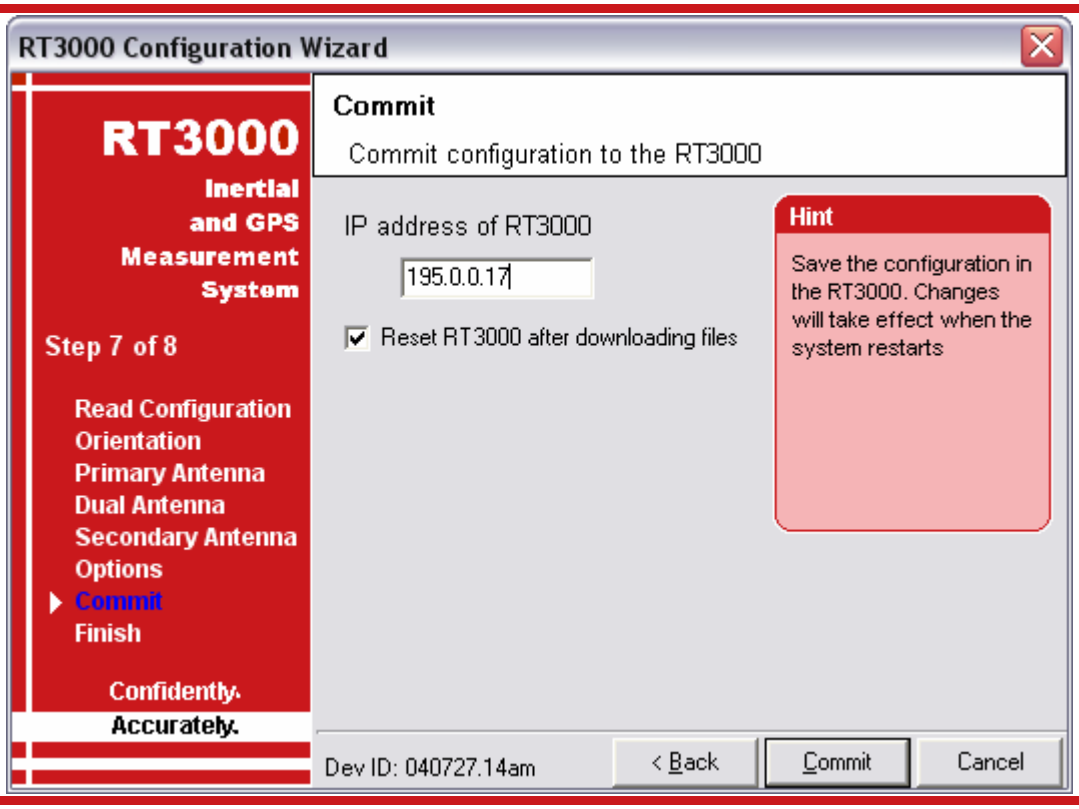


Committing the Configuration to the RT3000

The changes to the RT3000 settings must be performed using Ethernet. It is necessary to configure your computer's Ethernet settings so it is on the same network as the RT3000. If necessary, ask you system administrator to help.

Figure 20, below, shows the Commit screen.

Figure 20. `RT3000Cfg` Commit Screen



Enter the IP address of the RT3000 that you want to configure. The IP address is usually 195.0.0.*x* where *x* is the serial number of the RT3000.

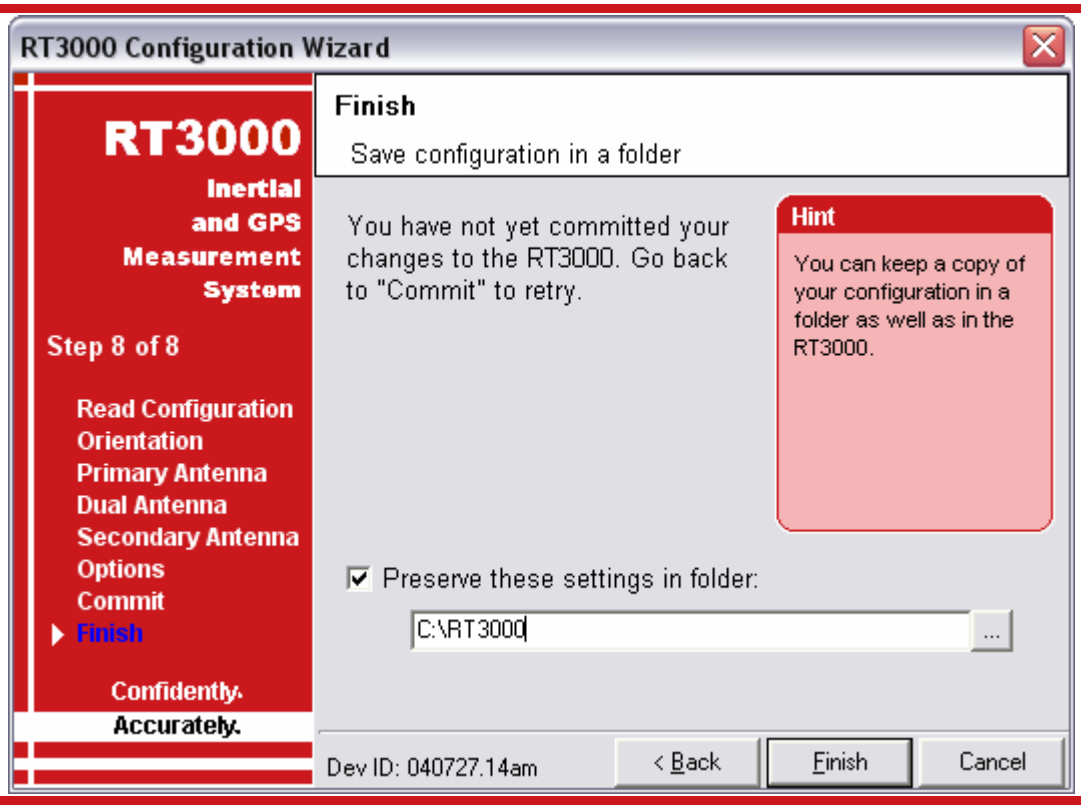
The changes to the configuration do not take effect until after the RT3000 is reset (or next power on). To reset the RT3000 after downloading check the *Reset RT3000 after downloading files* check box.

Press *Commit* to save the configuration on the RT3000.

Saving a copy of the settings locally

Before finishing it is possible to save a copy of the settings in a folder on your computer. This can then be reloaded next time. The Finish screen also lets you know if the settings have been committed successfully to the RT3000 or not. Figure 21, below, shows the Finish screen.

Figure 21. `RT3000Cfg` Finish Screen



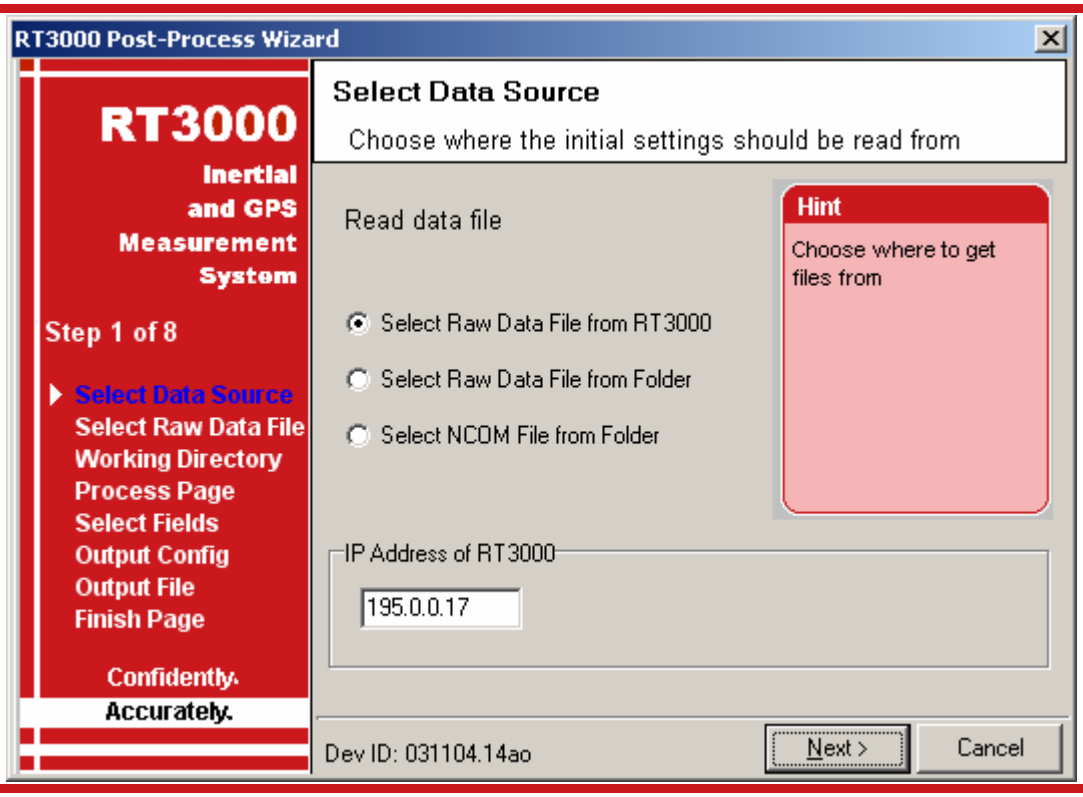
To save a copy of the settings in a local folder check the *Preserve these settings in folder* check box and enter the folder name.

RT3000 Post-Process Wizard

The data stored on the RT3000 is in a raw, unprocessed format; these files have an "rd" extension. The advantage of this is that it can be reprocessed with different configuration settings. For example, if the configuration was configured incorrectly when running in real-time then the configuration can be changed and the data can be reprocessed post-mission.

The RT3000 Post-Process Wizard can be used to reprocess the data. The RT3000 Post-Process Wizard also gives the user the ability to change the NCOM binary output format to text. Figure 22, below, shows the first step of the Wizard.

Figure 22. RT3000 Post-Process Wizard – Step 1



There are three options to the Wizard. The Wizard can load an "rd" file from the RT3000 and save it on the PC before processing the file. If the file has already been loaded on to the PC then the Wizard can process the file directly. If the file has already been processed (and is now in NCOM format) then it can change the file to text.

The RT3000 Post-Process Wizard if fairly self-explanatory. If additional help is required then please contact Oxford Technical Solutions.

Digital Inputs and Outputs

There are several different digital inputs and outputs available from the RT3000. Older systems, shipped with RT3000 User cables before 14C0038A only have one digital connection and this is normally configured as 1PPS.

The RT3000 User Cable 14C0038A gives the user several digital inputs and outputs. The normal configuration for these is listed in Table 14, below.

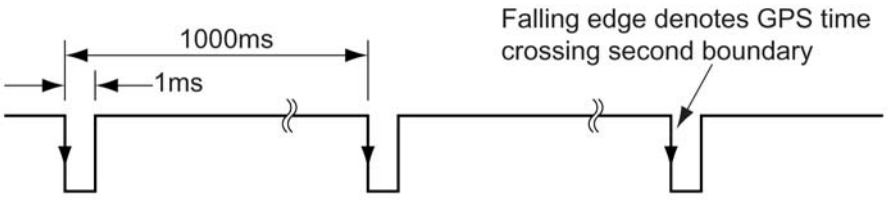
Table 14. 14C0038A RT3000 User Cable Digital Connections

Pin	Direction	Description
Digital 1	Output	1PPS from GPS receiver
Digital 2	Input	Event Input
Digital 3	Input	Wheel-Speed Input (from Tacho on a single wheel)
Digital 4	Output	Wheel-Speed Output simulation
Digital 5		Reserved

1PPS Output

The 1PPS output is a pulse from the GPS receiver. The falling edge of the pulse is the exact transition from one second to the next in GPS time. The pulse is low for 1ms then high for 999ms and repeats every second.

Figure 23. 1PPS Waveform



The output is a Low-Voltage CMOS output, with 0.8V or less representing a low and 2.4V or more representing a high. No more than 10mA should be drawn from this output. There is no protection on this output (protection circuitry would disturb the accuracy of the timing).

Event Input

The Event Input can be used to time events, like the shutter of a camera or a brake switch. No more than one event per second should be used. The Event Input has a pull-up resistor so it can be used with a switch or as a CMOS input. A Low-Voltage requires less than 0.8V on the input and a high voltage requires more than 2.4V on the input. There is no protection on this input (protection circuitry would disturb the accuracy of the timing). Keep the input in the range of 0V to 5V.

Wheel-Speed Input

The Wheel-Speed Input accepts TTL pulses from an encoder on a single wheel. An encoder from a gearbox should not be used, and simulated TTL pulses (e.g. from the CAN bus) should not be used. The timing of the Wheel-Speed Input pulses is critical and nothing should cause any delay in the Wheel-Speed Input pulses.

The Wheel-Speed Input requires less than 0.8V for a low pulse and more than 2.4V for a high pulse. Limited protection is provided on this port, however the input voltage should not exceed 12V.

Wheel-Speed Output

The Wheel-Speed Output generates pulses in the same way as a wheel encoder would. The configuration software can change the number of pulses per metre of travel. The output has 0.8V or less for a low and 2.4V or more for a high. There is no protection on this output, no more than 10mA should be used on this output.

Ethernet Configuration

To obtain maximum use of the RT3000 it is necessary to use the Ethernet connection. The operating system at the heart of the RT3000 product allows connection to the unit via FTP. The use of FTP allows the user to manage the data logged to the unit; files can be uploaded for reprocessing and deleted to make space for future files. Configuration files for alternative configurations require FTP to put the configuration files on to the RT3000.

The RT3000 outputs its data over Ethernet using a UDP broadcast. The use of a UDP broadcast allows everyone on the network to receive the data sent by the RT3000.

It is advisable to use the RT3000 on its own private network. This will help avoid loss of data through collisions on the network. Due to processing restrictions in the unit and collisions on the network it is advisable not to use the FTP services while the unit is being used to process data. The FTP server has a very low priority and will be slow while the RT3000 is running (i.e. while the top LED is green).

The settings of the RT3000's Ethernet adapter are given in Table 15, below.

Table 15. RT3000 Ethernet Settings

Setting	Value
IP Address	The IP Setting will be shown on the delivery note accompanying the RT3000.
Subnet Mask	255.255.255.0
FTP User	"user"
FTP User Password	"user"

For details on the output packet format of the UDP broadcast, contact Oxford Technical Solutions.

Connection Details

The RJ-45 connector on the 14C0038*x* User Interface Cable is designed to be connected directly to a network hub. To extend the cable it is necessary to use an "In-Line Coupler". This is two RJ-45 sockets wired together in a straight-through configuration. Following the "In-Line Coupler" a normal, straight UDP Cat 5e cable can be used to connect the coupler to the hub.

The RT3000 can also be connected directly to an Ethernet card in a computer. To do this a "Crossed In-Line Coupler" must be used. The connections in the crossed coupler are given in Table 16, below. Note that this is not the normal configuration sold and it may be necessary to modify an existing coupler to suit.

Table 16. In-Line Coupler Connections

Socket 1	Straight Socket 2	Crossed Socket 2
Pin 1	Pin 1	Pin 6
Pin 2	Pin 2	Pin 3
Pin 3	Pin 3	Pin 2
Pin 4	Pin 4	–
Pin 5	Pin 5	–
Pin 6	Pin 6	Pin 1
Pin 7	Pin 7	–
Pin 8	Pin 8	–

A typical In-Line Coupler is shown in Figure 24, below.

Figure 24. In-Line RJ-45 Coupler

Laboratory Testing

There are several checks that can be performed in the laboratory to ensure that the system is working correctly. The most fragile items in the system are the accelerometers, the other items are not subject to shock and do not need to be tested as thoroughly.

Accelerometer Test Procedure

To check that the accelerometers are working correctly, follow this procedure.

1. If there is a `mobile.vat` file in your system to convert from the RT3000 co-ordinate frame to the vehicle's co-ordinate frame then it needs to be removed and the system needs to be restarted.

2. Connect power to the system, connect the system to a laptop computer and run the visual display software (`ENGINUTIY.EXE`).

3. Orient the RT3000 in the following ways and check that the accelerations measurements are within the specifications shown in Table 17, below.

Table 17. Acceleration Measurement Specifications

Orientation			Acceleration Measurement
X	Y	Z	
Flat	Flat	Down	Z-Acceleration between –9.7 and –9.9m/s²
Flat	Flat	Up	Z-Acceleration between 9.7 and 9.9m/s²
Down	Flat	Flat	X-Acceleration between –9.7 and –9.9m/s²
Up	Flat	Flat	X-Acceleration between 9.7 and 9.9m/s²
Flat	Down	Flat	Y-Acceleration between –9.7 and –9.9m/s²
Flat	Up	Flat	Y-Acceleration between 9.7 and 9.9m/s²

This test is sufficient to ensure that the accelerometers have not been damaged. Typically a damaged accelerometer will read full scale (about 100m/s² or –100m/s²) or will not change its value.

Gyro Test Procedure

To check that the gyros (angular rate sensors) are working correctly, follow this procedure:

1. If there is a `mobile.vat` file in your system to convert from the RT3000 co-ordinate frame to the vehicle's co-ordinate frame then it needs to be removed and the system needs to be restarted.

2. Connect power to the system, connect the system to a laptop computer and run the visual display software (`ENGINUTIY.EXE`).

3. Rotate the RT3000 according to Table 18, below, and check that the angular rate measurements occur.

4. With the unit stationary, check that all the angular rates are within ±5°/s. (In general they will be within ±0.5°/s, but the algorithm in the RT3000 will work to specification with biases up to ±5°/s).

Table 18. Angular Rate Measurement Specifications

Rotation			Angular Rate Measurement
X	Y	Z	
+ve	Zero	Zero	X-direction should indicate positive rotation, others are small
–ve	Zero	Zero	X-direction should indicate negative rotation, others are small
Zero	+ve	Zero	Y-direction should indicate positive rotation, others are small
Zero	–ve	Zero	Y-direction should indicate negative rotation, others are small
Zero	Zero	+ve	Z-direction should indicate positive rotation, others are small
Zero	Zero	–ve	Z-direction should indicate negative rotation, others are small

It is hard to do a more exhaustive test using the angular rate sensors without specialised software and equipment. For further calibration testing it is necessary to return the unit to Oxford Technical Solutions.

Note that the RT3000 is capable of correcting the error in the angular rate sensors *very* accurately. It is not necessary to have very small values for the angular rates when stationary since they will be estimated during the initialisation process and warm-up period. This estimation process allows the RT3000 to go for long periods without requiring recalibration.

Testing the Internal GPS and other Circuitry

To check that all the internal circuits in the RT3000 are working correctly and that the navigation computer has booted correctly, use the following procedure:

1. Connect power to the system, connect the system to a laptop computer and run the visual display software (`ENGINUTIY.EXE`).

2. Use Table 19, below, to check that the status fields are changing.

Table 19. Status Field Checks

Field	Increment Rate
IMU Packets	100 per second
IMU Chars Skipped	Not changing (but not necessarily zero)
GPS Packets	Between 2 and 20 per second (depending on system)
GPS Chars Skipped	Not changing (but not necessarily zero)
GPS2 Packets	Between 2 and 20 per second (only for dual-GPS systems)
GPS2 Char Skipped	Not changing (but not necessarily zero)

These checks will ensure that the signals from the GPS and from the Inertial Sensors are being correctly received at the navigation computer.

Deriving further Measurements

The RT3000 outputs are complete for all aspects of vehicle motion apart from angular acceleration. There are instances when other outputs will be required, or when the same output is required in a different measurement co-ordinate frame. For example, you may wish to compute the following parameters:

1. compute velocity at a point remote from the RT3000 measurement point;
2. compute the slip angle of the vehicle;
3. compute the lateral acceleration perpendicular to gravity (so that vehicle roll does not affect the measurements);
4. plot position on a flat metric grid

Many of these outputs are computed using the RT-CAN unit or using the software provided. The equations are provided here to help understanding and to make it easier for engineers who need to write their own interpreters for the RT3000 output.

Before computing the additional outputs, you should have a clear understanding of the definitions of heading, pitch and roll. The RT3000 uses quaternions internally to avoid the problems of singularities and to minimise numerical drift on the attitude integration. Euler angles are used to output the heading, pitch and roll, and these have singularities at two orientations. The RT3000 has rules to avoid problems when operating close to the singularities; if you regenerate the rotation matrices given below then they will be correct.

The Euler angles output are three consecutive rotations (first heading, then pitch and finally roll) that transform a vector measured in the navigation co-ordinate frame to the body co-ordinate frame. The navigation co-ordinate frame is the orientation on the earth at your current location with axes of North, East and Down.

If V_n is vector V measured in the navigation co-ordinate frame and V_b is the same vector measured in the body co-ordinate frame the two vectors are related by:

$$V_n = C_{bn} \cdot V_b$$

$$V_n = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix} \cdot V_b$$

where:

ψ is the heading angle;

θ is the pitch angle and

ϕ is the roll angle.

Remember – heading, pitch and roll are usually output in degrees, but the functions *sin* and *cos* require these values in radians.

Computing a Velocity at a remote point

You can use the outputs of the RT3000 to compute the velocity at any other point on the vehicle (assuming that the vehicle is rigid). Velocity measurements from the RT3000 are expressed in the navigation co-ordinate frame, whereas the remote point is expressed in the body co-ordinate frame. The following formula relates the outputs of the RT3000 to a velocity at a remote point:

$$V2_n = V_n + C_{bn} \cdot \left(\omega_b \times \rho_b \right)$$

where:

$V2_n$ is the velocity at the remote point;

V_n is the velocity at the RT3000;

C_{bn} is the rotation matrix above;

ω_b is the angular rate vector in the body co-ordinate frame and

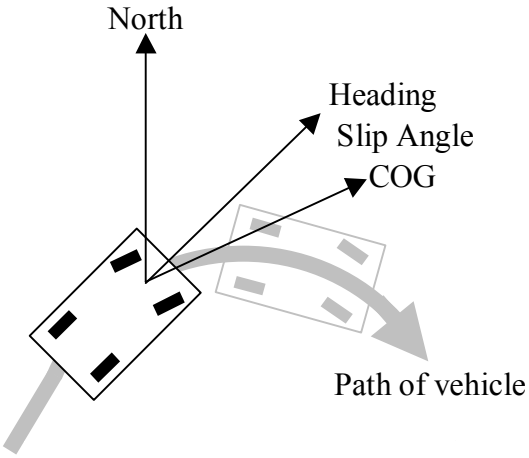
ρ_b is the distance from the RT3000 to the remote point expressed in the body co-ordinate frame.

The operator between ω_b and ρ_b is the cross-product operator.

Computing the Slip Angle

The Slip Angle is the difference between the Heading and the direction of travel over the ground.

Figure 25. Relationship between Heading, Slip Angle and COG



COG – Course over Ground, also known as Track or Vector.

In Figure 25, above, the Heading angle is the angle that the vehicle is *pointing* compared to North. The *Course over Ground* is the direction that the vehicle is going *over the ground*; this angle varies depending on the position in the car and it depends on whether the car is slipping across the surface of the road or not. The *Course over Ground* direction is also known as *Track*, *Track over Ground*, *Vector* or *Vector Velocity*.

The *Slip Angle* is the difference between the *Heading* and the *Course over Ground*.

To compute the Slip Angle it is necessary to compute the Track angle first. The track angle can be computed *only when speed is non-zero* using the four quadrant arc-tan function (usually called atan2):

$$\text{Track} = \text{atan2}\left(V_e, V_n\right) \cdot \frac{180}{\pi}$$

The Slip Angle is then:

$$\text{Slip} = \text{Heading} - \text{Track}$$

You should test the slip angle to make sure it is in the correct range (±180°). If not you will get large spikes in your data (for example, if heading is 0.1° and Course over Ground is 359.8° then you need to add 360° to your result).

Computing Forward and Lateral Velocities

Speed is the total rate of travel in any given direction. It can be expressed as a horizontal speed or a 3D speed. Forward Velocity is usually very close to speed, except when the vehicle skids. The Lateral Velocity is usually very close to zero, except when the vehicle skids.

The Forward and Lateral Velocities can be found by rotating the velocities in the navigation co-ordinate frame to be in the direction of the vehicle (using the heading angle). The rotation required to compute the Forward and Lateral Velocities are:

$$V_L = C_{Ln} \cdot V_n = \begin{bmatrix} \cos(\psi) & \sin(\psi) & 0 \\ -\sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot V_n$$

where:

V_L is the vector containing the Forward and Lateral Velocities (and Down Velocity);

C_{Ln} is the rotation matrix from the navigation co-ordinate frame to a level co-ordinate frame where the X-axis is aligned to the heading of the vehicle and

V_n is the velocity in the navigation co-ordinate frame.

Computing the Forward, Lateral and Down Accelerations

When the vehicle rolls, the Y-Acceleration measured in the body co-ordinate frame contains a component of gravity because the Y-direction is no longer at right angles to gravity. A roll angle as small as 1° gives a Y-acceleration of 0.171m/s² just from the coupling of gravity. The RT3000 can measure acceleration to 10mm/s² and has a resolution of about 0.1mm/s² at 100Hz (nearly 2000 times better than the gravity caused by a 1° rotation).

To compute the accelerations in a level co-ordinate frame (where gravity does not affect the acceleration measurements) use the following rotation:

$$A_L = C_{Lb} \cdot A_b = \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix} \cdot A_b$$

where:

A_L is the vector containing the Forward, Lateral and Down accelerations;

C_{Lb} is the rotation from the body co-ordinate frame to the level co-ordinate frame and

A_b is the vector of accelerations on the body co-ordinate frame.

Using a Flat Metric Grid

Because the earth is elliptical it is not possible to have distance in metres that make sense on the whole globe. Over a small, local area (for example, 10km) the effects of earth curvature can be ignored and a local, square grid can be used.

When working on a local grid the measurements for position will be expressed as Northings and Eastings (i.e. the number of metres North of an origin and the number of metres east of an origin). It is necessary to choose an origin where the Northings and Eastings are zero, we will call this the *base latitude* and the *base longitude*. Then we can compute the Northings and Eastings using the following equations:

$$\text{Northings} = (\text{Latitude} - \text{Base\_Latitude}) \cdot \left(6378137 \cdot \frac{\pi}{180}\right)$$

$$\text{Eastings} = (\text{Longitude} - \text{Base\_Longitude}) \cdot \left(6378137 \cdot \frac{\pi}{180}\right) \cdot \cos\left(\text{Base\_Latitude} \cdot \frac{\pi}{180}\right)$$

In each of these equations the Latitude, Longitude, Base Latitude and Base Longitude are all expressed in degrees. The Northings and Eastings are measured in metres.

Note that this equation is only an approximation. The true value of earth radius changes with location. 6378137 is an average value for the whole earth. For accurate measurements the exact radius at the Base Latitude and Base Longitude is required. If there is any altitude change then this may also need to be included.

Computing Performance Metrics

There are several methods of monitoring the performance from the RT3000. For each state a Kalman filter has there is a corresponding accuracy. In the RT3000 there are accuracies for all of the Kalman filter states. These are available in the NCOM output format.

The most useful quantities that measure performance of the system are the Position accuracies, the Velocity accuracies, the Heading, Pitch and Roll accuracy. Since these are 9 separate measurements, it is often useful to group them into fewer values that can be monitored.

Position Accuracy. In general it is best to monitor the *horizontal position accuracy*. This can be computed from the *North Position Accuracy* and the *East Position Accuracy* fields in the Status Information of the NCOM output. Use the formula:

$$\text{HorizontalPositionAccuracy} = \sqrt{\frac{\text{PosAccNorth}^2 + \text{PosAccEast}^2}{2}}$$

Velocity Accuracy. Similar to Position Accuracy, in general it is more useful to monitor the *horizontal velocity accuracy*. This can be computed from the *North Velocity Accuracy* and the *East Velocity Accuracy* fields in the Status Information of the NCOM output. Use the formulae:

$$\text{HorizontalVelocityAccuracy} = \sqrt{\frac{\text{VelAccNorth}^2 + \text{VelAccEast}^2}{2}}$$

$$\text{VelocityAccuracy} = \sqrt{\frac{\text{VelAccNorth}^2 + \text{VelAccEast}^2 + \text{VelAccDown}^2}{3}}$$

Orientation Accuracy. Since the Heading specification and the Pitch/Roll specifications are not the same, it is best to monitor the Orientation accuracy as a combined Pitch/Roll (attitude) accuracy and a separate Heading accuracy. To combine the Pitch/Roll accuracy use the formula:

$$\text{AttitudeAccuracy} = \sqrt{\frac{\text{PitchAcc}^2 + \text{RollAcc}^2}{2}}$$

The Heading accuracy is output directly by the RT3000.

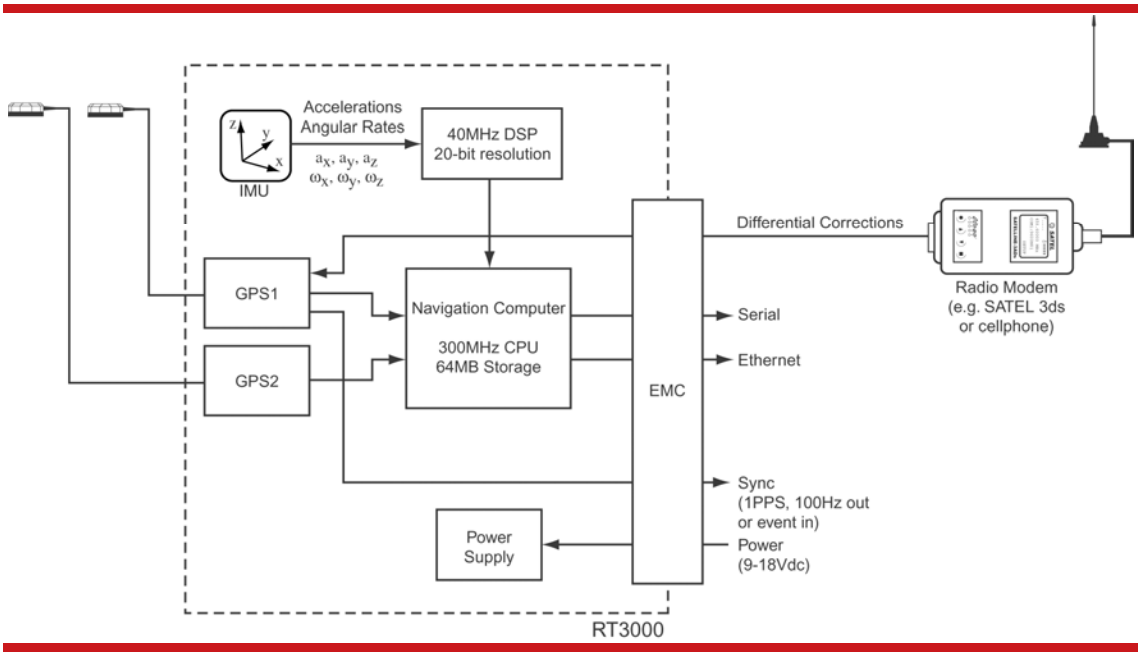
Operating Principles

This short section gives some background information on the components in the RT3000 and how they work together to give the outputs. A short overview of the algorithm is given and some explanation of how the software works. The section is provided as 'interesting information' and is not required for normal operation.

Internal Components

Figure 26, below, gives a schematic view of the components in the RT3000 system.

Figure 26. Schematic showing the internal components of the RT3000



The schematic shows the layout for a dual-antenna system, the second GPS (GPS2) and the second antenna are not fitted on single antenna systems.

The accelerations and angular rates are measured in the Inertial Measurement Unit (IMU). The accelerometers are all mounted at 90 degrees to each other so they can measure each direction independently. The three angular rate sensors are mounted in the same three directions as the accelerometers. A powerful, 40MHz floating point DSP controls the ADC and, through advanced signal processing, gives a resolution of 20-bits. Digital anti-aliasing filters and coning/sculling motion compensation algorithms are run on the DSP. Calibration of the accelerometers and angular rate sensors also takes place in the DSP; this includes very high precision alignment matrices that ensure

that the direction of the acceleration and angular rate measurements is accurate to better than 0.01 degrees.

The sampling process in the Inertial Measurement Unit is synchronised to GPS time so that the 100Hz measurements from the RT3000 are synchronised to GPS.

The Navigation Computer is a 300MHz CPU Pentium class processor that runs the navigation algorithms (more on this below). Information from the DSP and the two GPS receivers is fed into the Navigation Computer. The Navigation Computer runs a real-time operating system (QNX) so that the outputs are made in a deterministic amount of time. The outputs from the Navigation Computer are available over Serial RS232 or as a UDP broadcast on Ethernet.

The Sync pin on the output of the RT3000 is normally configured as a 1PPS output (directly from the GPS card). It may also be configured as a 100Hz sampling output or as an event input. As an event input the RT3000 is able to time when the input becomes closed-circuit. An internal pull-up resistor keeps the voltage high and the Sync pin can be connected directly to a brake switch or a camera shutter trigger. Accurate timing in the RT3000 can measure this event with 1μs resolution. No more than one event per second should be made.

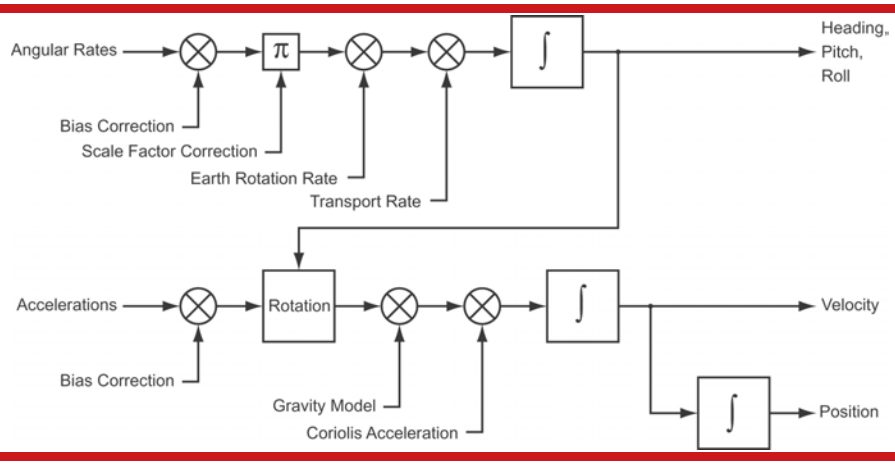
Differential corrections can be supplied directly to the GPS receiver to improve the positioning accuracy. The differential corrections can be supplied via radio modems from a base-station, via cell phones from a base-station or from a separate differential source, such as OmniStar or US Coast Guard.

Strapdown Navigator

The outputs of the system are derived directly from the Strapdown Navigator. The role of the Strapdown Navigator is to convert the measurements from the accelerometers and angular rate sensors to position. Velocity and orientation are also tracked and output by the Strapdown Navigator.

Figure 27, below, shows a basic overview of the Strapdown Navigator. Much of the detail has been left out and only the key elements are shown here.

Figure 27. Schematic of the Strapdown Navigator



(People familiar with Inertial Navigation Systems will note that 'Angular Rates' and 'Accelerations' are labelled as the inputs. In reality the DSP in the RT3000 converts these to 'Change in Angle' and 'Change in Velocity' to avoid problems of coning and sculling. Some other rotations are also missed in the diagram. The RT3000 does not use a wander angle, so it will not operate correctly on the North and South poles.)

The Angular Rates have their bias and scale factor corrections (from the Kalman Filter) applied. Earth Rotation Rate is also subtracted to avoid the 0.25 degrees per minute rotation of the earth. The Transport Rate is also corrected; this is the rate that gravity rotates by due to the vehicle moving across the earth's surface and it is proportional to horizontal speed. Finally the Angular Rates are integrated to give Heading, Pitch and Roll angles. These are represented internally using a Quaternion (so the RT3000 can work at any angle and does not have any singularities).

The Accelerations have their bias corrections (from the Kalman Filter) applied. Then they are rotated to give accelerations in the earth's co-ordinate frame (North, East Down). Gravity is subtracted and Coriolis acceleration effects removed. The accelerations are integrated to give velocity. This is integrated to give position.

The Strapdown Navigator uses a WGS-84 model of the earth, the same as GPS uses. This is an elliptical model of the earth rather than a spherical one. The position outputs are in degrees Latitude, degrees Longitude and Altitude. The Altitude is the distance from the model's earth sea level.

The Kalman filter used in the RT3000 is able to apply corrections to several places in the Strapdown Navigator, including Position, Velocity, Heading, Pitch, Roll, Angular Rate Bias and Scale factor and Acceleration Bias.

Kalman Filter

Kalman Filters can be used to merge several measurements of a quantity and therefore give a better overall measurement. This is the case with Position and Velocity in the RT3000; the Kalman filter is used to improve the Position measurement made from two sources, inertial sensors and GPS.

Using a model of how one measurement affects another the Kalman filter is able to estimate states where it has no direct measurement.

Consider a lift (or elevator) in a building. We might make measurements of acceleration and we might know what our position is when we pass a floor; these are the two measurements our system makes. A Kalman filter could be used to measure velocity in this situation even though no sensor measures velocity directly. The Kalman filter could also be used to measure the bias (or offset) of the accelerometer, thereby improving the system by providing on-line calibration. The bias of the accelerometer might mean that the system always believes that the lift arrives early at each floor; by changing the bias on the accelerometer the measurement of lift position can be made to correlate with the floor sensor more accurately.

The same principles are used in the RT3000. Position and Velocity are compensated directly, but other measurements like accelerometer bias, have no direct measurements. The Kalman filter *tunes* these so that the GPS measurements and the inertial measurements match each other as closely as possible.

The Kalman filter in the RT3000 has 24 states. These are position error (north, east, down); velocity error (north, east, down); heading error; pitch error; roll error; gyro bias (X, Y, Z); gyro scale factor (X, Y, Z); accelerometer bias (X, Y, Z); GPS antenna position (X, Y, Z); GPS antennas orientation (heading, pitch) and vehicle mounting angle (for Advanced Slip).

The errors are applied smoothly to the states. For example, if the Kalman filter wants to correct a position error of 5cm in the north direction then this is applied slowly, rather than jumping directly to the new position. This helps applications that use the RT3000 for control since any differential terms in the control algorithm do not have large step changes in them.

NCOM Packet Format

The NCOM packet format is a 72 byte packet, transmitted at 115,200 baud rate with 8 data bits, 1 stop bit and no parity. It has an optional low-latency format where the output can be derived after the first 22 characters have been received (1.9ms additional latency). More convenient processing of the data can be achieved after 62 characters have been received (5.3ms additional latency). Full functionality requires multiple packets to be received since low data rate information is divided up and sent in 8 bytes tagged on to the end of each packet.

To save space, many of the data packets are sent as 24-bit signed integer words; 16-bit precision does not provide the range/precision required for many of the quantities whereas 32-bit precision makes the packet much longer than required. All words are sent in little-endian format (meaning "little-end first" or "LSB first"), which is compatible with Intel microprocessors.

The packet is also transmitted over Ethernet as a 72-byte UDP broadcast. The port number is 3000. Ethernet provides the lowest latency output from the system since the transmission speed is nearly 1000 times faster than the serial communications.

Table 20. Word Length Definitions

Terminology	Data Length
Byte (UByte)	8-bit integer (unsigned)
Short (UShort)	16-bit integer (unsigned)
Word (UWord)	24-bit integer (unsigned)
Long (ULong)	32-bit integer (unsigned)
Float	32-bit IEEE float
Double	64-bit IEEE float

Note: If a 'U' precedes the value then it is unsigned, otherwise it is signed using 2's complement.

The definition of the packet is given in Table 21, Table 22 and Table 23, below.

Note that, to reduce the latency, the SYNC character, listed as the first character of the packet, is transmitted at the end of the previous cycle. On the communication link there will be a pause between the transmission of the SYNC and the next character. It is not advised to use this pause to synchronise the packet even though the operating system should guarantee the transmission timing of the packet.

Table 21. NCOM Packet Definition – Batch 1.

Byte	Quantity	Notes
0	Sync	Always E7h
1 2	Time Time	Time is transmitted as milliseconds into the minute in GPS time. Range is 0 to 59,999 ms. The packets are always transmitted at 100Hz, use this quantity to verify that a packet has not been dropped.
3 4 5	Acceleration X LSB Acceleration X Acceleration X MSB	Acceleration X is the *vehicle body-frame* acceleration in the x-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-4} m/s².
6 7 8	Acceleration Y LSB Acceleration Y Acceleration Y MSB	Acceleration Y is the *vehicle body-frame* acceleration in the y-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-4} m/s².
9 10 11	Acceleration Z LSB Acceleration Z Acceleration Z MSB	Acceleration Z is the *vehicle body-frame* acceleration in the z-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-4} m/s².
12 13 14	Angular Rate X LSB Angular Rate X Angular Rate X MSB	Angular Rate X is the *vehicle body-frame* angular rate in the x-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-5} radians/s.
15 16 17	Angular Rate Y LSB Angular Rate Y Angular Rate Y MSB	Angular Rate Y is the *vehicle body-frame* angular rate in the y-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-5} radians/s.
18 19 20	Angular Rate Z LSB Angular Rate Z Angular Rate Z MSB	Angular Rate Z is the *vehicle body-frame* angular rate in the z-direction (i.e. after the *IMU to Vehicle Attitude* matrix has been applied). It is a signed word in units of 10^{-5} radians/s.
21	Nav. Status	See Table 1, below.
22	Checksum 1	This checksum allows the software to verify the integrity of the packet so far. For a low-latency output the accelerations and angular rates can be used to quickly update the previous solution. Contact Oxford Technical Solutions for source code to perform this function.

Table 22. NCOM Packet Definition – Batch 2.

Byte	Quantity	Notes
23	Latitude (Byte 0)	The Latitude of the IMU. It is a double in units of radians.
24	Latitude (Byte 1)	
25	Latitude (Byte 2)	
26	Latitude (Byte 3)	
27	Latitude (Byte 4)	
28	Latitude (Byte 5)	
29	Latitude (Byte 6)	
30	Latitude (Byte 7)	
31	Longitude (Byte 0)	Longitude of the IMU. It is a double in units of radians.
32	Longitude (Byte 1)	
33	Longitude (Byte 2)	
34	Longitude (Byte 3)	
35	Longitude (Byte 4)	
36	Longitude (Byte 5)	
37	Longitude (Byte 6)	
38	Longitude (Byte 7)	
39	Altitude (Byte 0)	Altitude of the IMU. It is a float in units of metres
40	Altitude (Byte 1)	
41	Altitude (Byte 2)	
42	Altitude (Byte 3)	
43	North Velocity (LSB)	North Velocity in units of 10^{-4} m/s.
44	North Velocity	
45	North Velocity (MSB)	
46	East Velocity (LSB)	East Velocity in units of 10^{-4} m/s.
47	East Velocity	
48	East Velocity (MSB)	
49	Down Velocity (LSB)	Down Velocity in units of 10^{-4} m/s.
50	Down Velocity	
51	Down Velocity (MSB)	
52	Heading (LSB)	Heading in units of 10^{-6} radians. Range $\pm\pi$.
53	Heading	
54	Heading (MSB)	

Byte	Quantity	Notes
55	Pitch (LSB)	Heading in units of 10^{-6} radians. Range $\pm\pi/2$.
56	Pitch	
57	Pitch (MSB)	
58	Roll (LSB)	Heading in units of 10^{-6} radians. Range $\pm\pi$.
59	Roll	
60	Roll (MSB)	
61	Checksum 2	This checksum allows the software to verify the integrity of the packet so far. For a medium-latency output the full navigation solution is available. Only low-rate information is transmitted next.

Table 23. NCOM Packet Definition – Batch 3.

Byte	Quantity	Notes
62	Channel	The channel number determines what information is sent in Bytes 0 to 7 below.
63	Byte 0	
64	Byte 1	
65	Byte 2	
66	Byte 3	
67	Byte 4	
68	Byte 5	
69	Byte 6	
70	Byte 7	
71	Checksum 3	This is the final checksum that verifies the packet.

See the section on Status Information for the information included in Batch 3.

Table 24. NCOM Navigation Status – Byte 21

Value	Description
0	All quantities in the packet are invalid.
1	Raw IMU measurements. These are output at roughly 10Hz intervals before the system is initialised. They are useful for checking the communication link and for verifying the operation of the accelerometers and angular rate sensors in the laboratory. In this mode *only* the accelerations and angular rates are valid, they are not calibrated or to any specification. The information in the other fields is invalid.
2	Initialising. When GPS time becomes available the system starts the initialisation process. The strapdown navigator and kalman filter are allocated, but do not yet run. Angular Rates and Accelerations during this time are output 1s in arrears. There will be a 1s pause at the start of initialisation where no output will be made (while the system fills the buffers). The system has to run 1s in arrears at this time in order to synchronise the GPS data with the inertial data and perform the initialisation checks. During the Initialising mode the Time, Acceleration and Angular Rate fields will be valid.
3	Locking. The system will move to the locking mode if: b. The velocity exceeds 5 m/s or c. The dual-antenna GPS locks a suitable heading solution. In locking mode the system runs in arrears but catches up by 0.1s every 1s; locking mode lasts 10s. During locking mode the outputs are not real-time.
4	Locked. In Locked mode the system is outputting real-time data with the specified latency guaranteed. All fields are valid.
5 – 255	Reserved

Status Information

Batch 3 of the NCOM packet transmits the Status information on the RT3000. There is a lot of internally used information in the Status Information, but some of this information is useful customers.

The Status Information is transmitted at a low rate. Each cycle a different set of 8-bytes are transmitted. The *Channel* field defines which set of information is included in the 8-bytes.

Some of the Status fields have special bits or values that denote ‘invalid’. The invalid values or the validity bits are noted in the tables.

Table 25. NCOM Packet Definition – Batch 3

Channel	Information	See
0	Full Time, Number of Satellites, Position Mode, Velocity Mode, Dual-Antenna Mode	Table 26
1	Kalman Filter Innovations	Table 27
2	Internal Information about GPS1	–
3	Position Accuracy	Table 29
4	Velocity Accuracy	Table 30
5	Orientation Accuracy	Table 31
6	Gyro Bias	Table 32
7	Accelerometer Bias	Table 33
8	Gyro Scale Factor	Table 34
9	Gyro Bias Accuracy	–
10	Accelerometer Bias Accuracy	–
11	Gyro Scale Factor Accuracy	–
12	Position estimate of the Primary GPS antenna	Table 35
13	Orientation estimate of Dual-Antenna systems	Table 36
14	Accuracy of Position of the Primary GPS antenna	Table 37
15	Accuracy of the Orientation of Dual-antenna systems	Table 38
16	RT3000 to Vehicle Rotation (from initial setting defined by user)	Table 39
17	Internal Information about GPS2	–
18	Internal Information about Inertial Measurement Unit	–
19	Software version running on RT3000	Table 40
20	Age of Differential Corrections	Table 41
21	Disk Space, Size of current internal log file	Table 42
22	Internal Information on timing of real-time processing	–
23	System Up Time, Number of consecutive GPS rejections	–
24	Trigger Event Timing	–
25	Reserved	–
26	Reserved	–
27	Internal Information about Dual-Antenna Ambiguity Searches	–
28	Internal Information about Dual-Antenna Ambiguity Searches	–
29	Details on the initial settings	–
30-255	*continued on next page*	

Note: Channels with no corresponding table are not described in this manual. Contact Oxford Technical Solutions if you require specific information on these channels.

Table 25. NCOM Packet Definition – Batch 3, continued

Channel	Information	See
30	Operating System and script version information	–
31	Hardware Configuration Information	–
32	Zero Velocity and Advanced Slip Innovations	–
33	Zero Velocity Lever Arm	–
34	Zero Velocity Lever Arm Accuracy	–
35	Advanced Slip Lever Arm	–
36	Advanced Slip Lever Arm Accuracy	–
37	Advanced Slip Alignment Angle	–
38	Zero Velocity Option Settings	–
39	Zero Velocity Option Settings	–
40	Reserved	–
41	Output Baud Rates	–
42	Heading Lock Options	–
43	Trigger2 Event Timing	–
44	Wheel Speed Configuration	–
45	Wheel Speed Counts	–
46	Wheel Speed Lever Arm	–
47	Wheel Speed Lever Arm Accuracy	–
48	Undulation, DOP of GPS	Table 43
49	OmniStar Tracking Information	Table 44
48-255	Reserved for future use.	–

Note: Channels with no corresponding table are not described in this manual. Contact Oxford Technical Solutions if you require specific information on these channels.

Table 26. Status Information, Channel 0

Bytes	Format	Definition	Invalid When
0–3	Long	Time in minutes since GPS began (midnight 06/01/1980)	Value < 1000
4	UChar	Number of GPS satellites tracked by the Primary GPS receiver	Value = 255
5	UChar	Position Mode of Primary GPS	Value = 255
6	UChar	Velocity Mode of Primary GPS	Value = 255
7	UChar	Orientation Mode of Dual-Antenna Systems	Value = 255

Note: For the definitions of Position Mode, Velocity Mode and Orientation Mode see below.

Table 27. Definitions of Position Mode, Velocity Mode and Orientation Mode

Value	Definition
0	None. The GPS is not able to make this measurement
1	Search. The GPS system is solving ambiguities and searching for a valid solution
2	Doppler. The GPS measurement is based on a Doppler Measurement
3	Stand-Alone. The GPS measurement has no additional external corrections
4	Differential. The GPS measurement used code-phase differential corrections
5	RTK Float. The GPS measurement used L1 Carrier-phase differential corrections to give a floating ambiguity solution.
6	RTK Integer. The GPS measurement used L1/L2 Carrier-phase differential corrections to give an integer ambiguity solution
7	SBAS
8	OmniStar VBS
9	OmniStar HP
10	SBAS-L2 *(not operational yet)*
11 – 255	Reserved or Invalid.

Table 28. Status Information, Channel 1

Bytes	Format	Definition	Valid When
0	Char	Bits 1 to 7: Position X Innovation	Bit 0 = 1
1	Char	Bits 1 to 7: Position Y Innovation	Bit 0 = 1
2	Char	Bits 1 to 7: Position Z Innovation	Bit 0 = 1
3	Char	Bits 1 to 7: Velocity X Innovation	Bit 0 = 1
4	Char	Bits 1 to 7: Velocity Y Innovation	Bit 0 = 1
5	Char	Bits 1 to 7: Velocity Z Innovation	Bit 0 = 1
6	Char	Bits 1 to 7: Orientation Pitch Innovation	Bit 0 = 1
7	Char	Bits 1 to 7: Orientation Heading Innovation	Bit 0 = 1

Note: The innovations are always expressed as a proportion of the current accuracy. Units are 0.1 σ. As a general rule, innovations below 1.0σ are good; innovations above 1.0σ are poor. Usually it is best to filter the square of the innovations and display the square root of the filtered value.

Note 2: If the Orientation Pitch Innovation and/or the Orientation Heading Innovation are always much higher than 1.0σ then it is likely that the system or the antennas have changed orientation in the vehicle. (Or the environment is too poor to use the dual-antenna system).

Table 29. Status Information, Channel 3

Bytes	Format	Definition	Valid When
0 – 1	Short	North Position Accuracy	Age < 150
2 – 3	Short	East Position Accuracy	Age < 150
4 – 5	Short	Down Position Accuracy	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Position Accuraccies are 1mm.

Table 30. Status Information, Channel 4

Bytes	Format	Definition	Valid When
0 – 1	Short	North Velocity Accuracy	Age < 150
2 – 3	Short	East Velocity Accuracy	Age < 150
4 – 5	Short	Down Velocity Accuracy	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Velocity Accuracies are 1mm/s.

Table 31. Status Information, Channel 5

Bytes	Format	Definition	Valid When
0 – 1	Short	Heading Accuracy	Age < 150
2 – 3	Short	Pitch Accuracy	Age < 150
4 – 5	Short	Roll Accuracy	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Orientation Accuracies are 1e-5 radians.

Table 32. Status Information, Channel 6

Bytes	Format	Definition	Valid When
0 – 1	Short	Gyro Bias X	Age < 150
2 – 3	Short	Gyro Bias Y	Age < 150
4 – 5	Short	Gyro Bias Z	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Gyro Biases are 5e-6 radians.

Table 33. Status Information, Channel 7

Bytes	Format	Definition	Valid When
0 – 1	Short	Accelerometer Bias X	Age < 150
2 – 3	Short	Accelerometer Bias Y	Age < 150
4 – 5	Short	Accelerometer Bias Z	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Accelerometer Biases are 0.1mm/s².

Table 34. Status Information, Channel 8

Bytes	Format	Definition	Valid When
0 – 1	Short	Gyro Scale Factor X	Age < 150
2 – 3	Short	Gyro Scale Factor Y	Age < 150
4 – 5	Short	Gyro Scale Factor Z	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Gyro Scale Factors are 1ppm (0.0001%).

Table 35. Status Information, Channel 12

Bytes	Format	Definition	Valid When
0 – 1	Short	Distance to Primary GPS Antenna in X direction	Age < 150
2 – 3	Short	Distance to Primary GPS Antenna in Y direction	Age < 150
4 – 5	Short	Distance to Primary GPS Antenna in Z direction	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Distances are 1mm.

Table 36. Status Information, Channel 13

Bytes	Format	Definition	Valid When
0 – 1	Short	Heading Orientation of the GPS Antennas	Age < 150
2 – 3	Short	Pitch Orientation of the GPS Antennas	Age < 150
4 – 5	Short	Distance between the GPS Antennas	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the distances are 1mm. The units of the Orientation Angles are 1e-4 radians.

Table 37. Status Information, Channel 14

Bytes	Format	Definition	Valid When
0 – 1	Short	Accuracy of Distance to Primary GPS Antenna in X direction	Age < 150
2 – 3	Short	Accuracy of Distance to Primary GPS Antenna in Y direction	Age < 150
4 – 5	Short	Accuracy of Distance to Primary GPS Antenna in Z direction	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the Distance Accuracies are 0.1mm.

Table 38. Status Information, Channel 15

Bytes	Format	Definition	Valid When
0 – 1	Short	Accuracy of Heading Orientation of the GPS Antennas	Age < 150
2 – 3	Short	Accuracy of Pitch Orientation of the GPS Antennas	Age < 150
4 – 5	Short	Accuracy of Distance between the GPS Antennas	Age < 150
6	UChar	Age	
7		Reserved	

Note: The units of the distances are 1mm. The units of the Orientation Angle Accuracies are 1e-4 radians.

Table 39. Status Information, Channel 16

Bytes	Format	Definition	Valid When
0 – 1	Short	Heading of the vehicle in the RT3000 co-ordinate frame.	Byte 6 = 0
2 – 3	Short	Pitch of the vehicle in the RT3000 co-ordinate frame.	Byte 6 = 0
4 – 5	Short	Roll of the vehicle in the RT3000 co-ordinate frame.	Byte 6 = 0
6	UChar	Validity	
7	Char	Bits 1–7 UTC Time Offset	Bit 0 = 1

Note: The units of the Orientation Angles are 1e-4 radians. To compute UTC Time from GPS Time *add* the offset. Currently the offset is –13 seconds. (The offset is always an integer number of seconds. UTC Time slips or gains a second occasionally whereas GPS Time does not).

Table 40. Status Information, Channel 19

Bytes	Format	Definition	Valid When
0 – 7	8 x Char	This is the Software Version or *Development ID* that is running in the RT3000 in ASCII format.	

Table 41. Status Information, Channel 20

Bytes	Format	Definition	Valid When
0 – 1	Short	Age of the Differential Corrections from the Base-Station	
2 – 5	4 x Char	Differential Station ID	
6 – 7		Reserved	

Note: The unit of the Differential Corrections is 0.01 seconds.

Table 42. Status Information, Channel 21

Bytes	Format	Definition	Valid When
0 – 3	Long	Disk Space Remaining on RT3000. Note that the RT3000 always leaves about 20K spare on the disk.	Value > 0
4 – 7	Long	Size of current logged raw data file. When there is insufficient space on the disk no more data will be written.	Value > 0

Note: The values are output in kilobytes.

Table 43. Status Information, Channel 48

Bytes	Format	Definition	Valid When
0 – 1	Short	Undulation value (difference between RT3000 Altitude and WGS-84 Ellipsoidal Altitude)	Value not 0xFFFF
2	UChar	HDOP of GPS	Value not 0xFF
3	UChar	PDOP of GPS	Value not 0xFF
4 – 7		Reserved	

Units of Undulation are 5mm. Units of HDOP/PDOP are 0.1.

Table 44. Status Information, Channel 49

Bytes	Format	Definition	Valid When
0 – 1	UShort	Frequency of OmniStar Tracking Loop	Value not 0xFFFF
2	UChar	SNR of OmniStar signal	Value not 0xFF
3	UChar	Time of continuous tracking of OmniStar signal	Value not 0xFF
4	UChar	OmniStar Status	Value not 0xFF
5 – 7		Reserved	

The Frequency of the OmniStar Tracking Loop is 1.52 + (Value / 1e6) GHz. Units of SNR is 0.2dB. Units of Time for tracking of OmniStar signal is 1.0 seconds.

CAN Messages and Signals

The RT-CAN uses identifiers 500h to 5FFh for RT3000 Status Information and 600h to 60Fh for navigation information.

All values from the RT3000 are encoded in Little-Endian format (Intel-style).

Termination Resistor

The CAN bus output does not include a termination resistor. It is essential to include a 120Ω resistor at each end of your CAN bus. Otherwise the CAN bus will not work.

CAN-DB File

A CAN-DB file is available for download on the Oxford Technical Solutions web site. This file contains definitions for the Status messages as well as the Measurement outputs. Only the Measurement outputs are described here.

CAN Bus Messages

Table 45, below, lists all the messages that the RT3000 puts on the CAN bus and the identifiers that are used for the messages. The signals in each message are listed in the tables that follow.

Table 45. CAN Bus Messages

Identifier (hex)	Data Contents	See Table
500h to 5FFh	Reserved for RT3000 Status Information	See NCOM Status Channel[1]
600h	Date and Time	Table 46
601h	Latitude, Longitude	Table 47
602h	Altitude	Table 48
603h	Velocity (North East Down)	Table 49
604h	Velocity (Forward/Lateral)	Table 50
605h	Accelerations (body X, Y, Z)	Table 51
606h	Accelerations (Forward, Lateral, Down)	Table 52
607h	Heading, Pitch Roll	Table 53
608h	Angular Rates (body X, Y, Z)	Table 54
609h	Angular Rates (Forward, Pitch, Yaw)	Table 55
60Ah	Slip Angle, Track Angle	Table 56
60Bh	Distance	Table 57
60Ch	XY Position in Local Co-ordinates	Table 58
60Dh	XY Velocity, Yaw Angle, in Local Co-ordinates	Table 59
60Eh	Angular Acceleration (body X, Y, Z)	Table 60
60Fh	Angular Acceleration (Forward, Pitch, Yaw)	Table 61
610h-614h	Reserved for RT-ANA signals	

Note 1: The Status Information in NCOM is output over the CAN bus on Identifiers 500h to 5FFh. The offset from 500h is the same as the *Channel* number in the NCOM message definition. The bytes 0 – 7 are the same in the CAN message as in the NCOM packet.

Table Heading Definitions

The fields in the tables have the following meanings.

Offset (bits). This is the offset into the Message where the Signal starts. To compute the offset in bytes divide the value by 8.

Length (bits). This is the length of the Signal in bits. To compute the length of the Signal in bytes, divide the value by 8.

Type. This specifies either an unsigned value (U) or a signed value (S).

Units. This is the units for the signal.

Factor. This it the factor that the integer unit should be multiplied by to get the Signal into the units given in the table.

Offset. This is the value of the Signal when the integer value in the CAN message is zero. It is zero for all the RT3000 signals and can usually be discarded.

Signals

The following tables describe the signals in each of the messages.

Table 46. Identifier 600h (1536), Date and Time

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	8	U	year	1	0	Year within century (e.g. '2' during year 2002)
8	8	U	year	100	0	Century (e.g. '20' during 2002)
16	8	U	month	1	0	Month
24	8	U	day	1	0	Day
32	8	U	s	0.01	0	Hundredths of a Second
40	8	U	s	1	0	Seconds
48	8	U	min	1	0	Minutes
56	8	U	hour	1	0	Hours

Note: Time is always reported as GPS time. Currently this is 13 seconds different from UTC

Table 47. Identifier 601h (1537), Latitude and Longitude

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	32	S	degrees	1e-7	0	Latitude
32	32	S	degrees	1e-7	0	Longitude

Table 48. Identifier 602h (1538), Altitude

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	32	S	m	0.001	0	Attitude

Table 49. Identifier 603h (1539), Velocity

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	m/s	0.01	0	North Velocity
16	16	S	m/s	0.01	0	East Velocity
32	16	S	m/s	0.01	0	Down Velocity
48	16	S	m/s	0.01	0	Horizontal Speed

The Horizontal Speed is the vector addition of North and East Velocities. For Forward Speed (which can go negative) see message 604h.

Table 50. Identifier 604h (1540), Velocity in Level Frame

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	m/s	0.01	0	Forward Velocity
16	16	S	m/s	0.01	0	Lateral Velocity (Right positive)

The Forward Speed can go negative when driving backwards.

Table 51. Identifier 605h (1541), Body Accelerations

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	m/s²	0.01	0	Body X-Acceleration
16	16	S	m/s²	0.01	0	Body Y-Acceleration
32	16	S	m/s²	0.01	0	Body Z-Acceleration

Table 52. Identifier 606h (1542), Level Accelerations

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	m/s²	0.01	0	Forward Accelerations
16	16	S	m/s²	0.01	0	Lateral Acceleration (Right positive)
32	16	S	m/s²	0.01	0	Down Acceleration

Table 53. Identifier 607h (1543), Heading, Pitch, Roll

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	U	degrees	0.01	0	Heading
16	16	S	degrees	0.01	0	Pitch
32	16	S	degrees	0.01	0	Roll

Note: the range of Heading is 0 to 360 degrees; the range of pitch is ±90 degrees; the range of roll is ±180 degrees.

Table 54. Identifier 608h (1544), Body X, Y, Z Angular Rates

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	deg/s	0.01	0	Body X-Angular Rate (Roll Angular Rate)
16	16	S	deg/s	0.01	0	Body Y-Angular Rate
32	16	S	deg/s	0.01	0	Body Z-Angular Rate

Table 55. Identifier 609h (1545), Level Angular Rates

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	deg/s	0.01	0	Forward Angular Rate
16	16	S	deg/s	0.01	0	Pitch Angular Rate
32	16	S	deg/s	0.01	0	Yaw Angular Rate

See message 608h for Roll Angular Rate. The definition of roll rate used in this manual is consistent with the Euler Angles used to output Roll, Pitch and Heading; therefore the Roll Angular Rate is the same as the pitched X-Angular Rate or the Body X-Angular Rate. The Forward Angular Rate is the rotation about the axis which is horizontal.

Table 56. Identifier 60Ah (1546), Track, Slip Angles

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	U	degrees	0.01	0	Track Angle
16	16	S	degress	0.01	0	Slip Angle

Note that the Slip Angle will be close to 180 degrees when driving backwards.

Table 57. Identifier 60Bh (1547), Distance

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	32	U	m	0.001	0	Distance with Hold
32	32	U	m	0.001	0	Distance

Note: The "Distance with Hold" will not increase when the RT3000 measures a speed less than 0.2m/s whereas the "Distance" field will drift by the noise of the RT3000 when stationary. The distances start from zero when the RT-CAN unit is powered up.

Table 58. Identifier 60Ch (1548), XY Position in Local Co-ordinates

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	32	U	m	0.0001	0	X Distance from Origin
32	32	U	m	0.0001	0	Y Distance from Origin

Notes: The Origin is set using the Local Co-ordinates option of the RT3000 Configuration Software. The convention used for the Local Co-ordinates uses a right-handed set with the Z-axis *up*.

Table 59. Identifier 60Dh (1549), XY Velocity, Yaw Angle in Local Co-ordinates

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	m/s	0.01	0	X Velocity
16	16	S	m/s	0.01	0	Y Velocity
32	16	S	degrees	0.01	0	Yaw Angle
48	16	S	degrees	0.01	0	Track Angle in Local Co-ordinates

Note: The convention used for the Local Co-ordinates uses a right-handed set with the Z-axis *up*.

Table 60. Identifier 60Eh (1550), Body X, Y, Z Angular Accelerations

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	deg/s²	0.1	0	Body X-Angular Accelerations (Roll Angular Accelerations)
16	16	S	deg/s²	0.1	0	Body Y-Angular Accelerations
32	16	S	deg/s²	0.1	0	Body Z-Angular Accelerations

Table 61. Identifier 60Fh (1551), Level Angular Accelerations

Offset (bits)	Length (bits)	Type	Units	Factor	Offset	Description
0	16	S	deg/s²	0.1	0	Forward Angular Accelerations
16	16	S	deg/s²	0.1	0	Pitch Angular Accelerations
32	16	S	deg/s²	0.1	0	Yaw Angular Accelerations

Revision History

Table 62. Revision History

Revision	Comments
011211	Draft.
020225	Draft. Added NCOM description.
020528	Reflects the modification of the system to use RTCA corrections instead of CMR. Upgrade to the specification.
021021	Added information about initialisation, deriving additional outputs. Changed operating temperature specification to 50degC. Added Lab. Test procedures
030131	Specification Changes, Dual-Antenna now simpler, other small changes
030331	Clarified antenna type supplied. Added section on 'Operating Principles'
030401	Added Status Information, Computing Performance Metrics and `RT300Cfg`.
030407	Corrections. Dual-antenna Multi-path explanation.
030522	Changed small RT3000 dimensions, height increased from 63 to 68mm.
030623	Added RT-Base references.
030728	Added CAN-Inside option; Advanced Slip; OmniStar configuration.
031112	Added Heading Lock; Garage Mode and other optional features to RT3000Cfg. Added RT3000 Post-Process Wizard.
040211	Added RT3200 Product
040803	UDP port 3000 now used instead of port 17. Renamed "Vehicle frame" as "Level frame" for CAN messages to avoid confusion.. Added XY Position/Velocity CAN messages. Updated for new configuration options – Distance Output, Analogue Output, Angular Acceleration Filter, Wheel Speed Input, Local Co-ordinates. Updated fields in NCOM status information.
041021	Added information on 14C0038A and the Digital Inputs/Outputs.
041116	Added information on Angular Acceleration, Undulation, PDOP/HDOP, OmniStar Tracking, 1PPS waveform.
041213	Changes relating to the new RT3000 Configuration Software. Additional information on Dual-Antenna systems and OmniStar.
050304	RT3080 added. Updated for new Orientation Technique in RT3000Cfg. Other small corrections.

Drawing List

Table 63, below, lists the available drawings that describe components of the RT3000 system. Many of these drawings are attached to the back of this manual. Note that the '*x*' following a drawing number is the revision code for the part. If you require a drawing, or different revision of a drawing, that is not here then contact Oxford Technical Solutions.

Table 63. List of Available Drawings

Drawing	Description
14A0004*x*	Single Antenna RT3000 System Outer Dimension Drawings. Available as an option for single antenna systems.
14A0007*x*	RT3000 System Outer Dimension Drawing.
14C0009*x*	RT3000 User Interface Cable
14C0016*x*	RT3000 Radio Modem Interface Cable
14C0021*x*	RT3000 User Interface Cable
14C0023*x*	RT3000 User Interface Cable
14C0033x	RT3000 User Interface Cable
14C0038A	RT3000 User Interface Cable
14C0019*x*	Base-Station Radio Modem/Power Cable
14C0018x	M12 Power Cable
PowerPak-II	Base-Station GPS Receiver
GPS-600	GPS Antenna
AT575-70B	GPS Antenna

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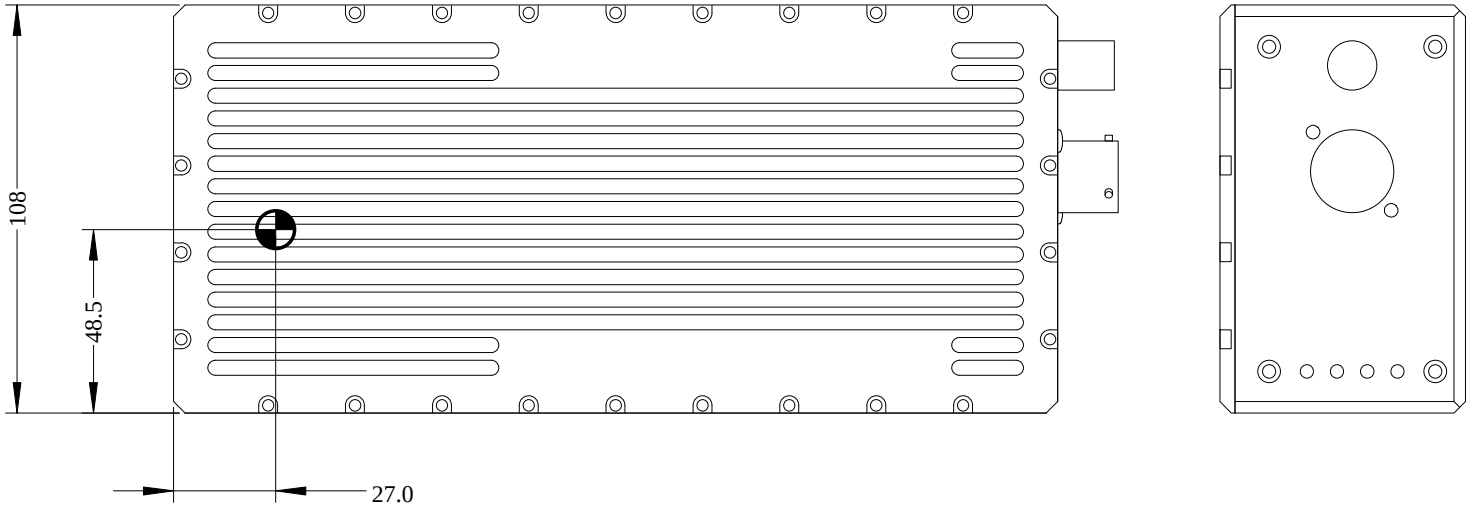

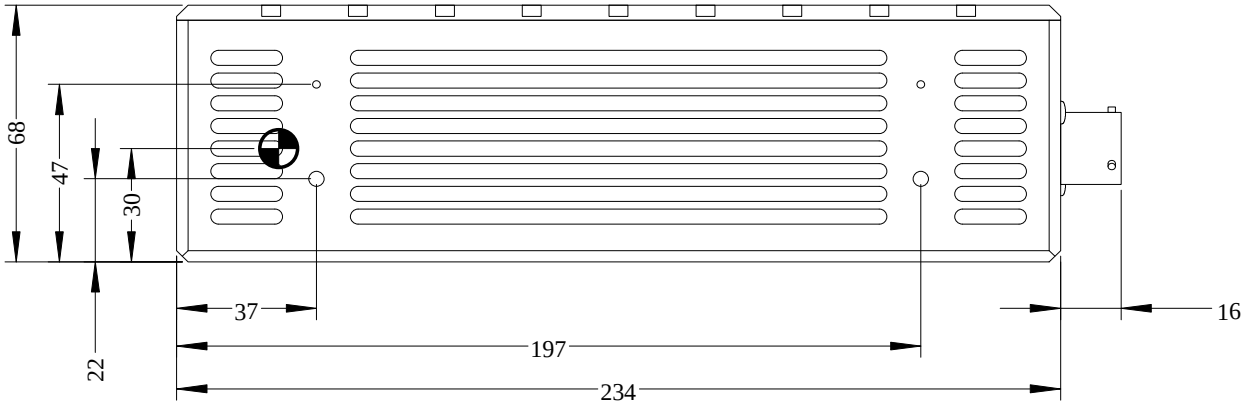

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0 10 20 30

Print Size:	A4
Scale:	1:2
Units:	mm
Tolerances:	All 0.1
Material:	HE30
Finish:	Red Anodised
Projection:	3rd Angle

Notes:

Revision History:

B - Changed Height

Date:	22/05/2003
Part #:	14A0004B
Document:	RT3000 Dimensions
Sheet:	1 of 1

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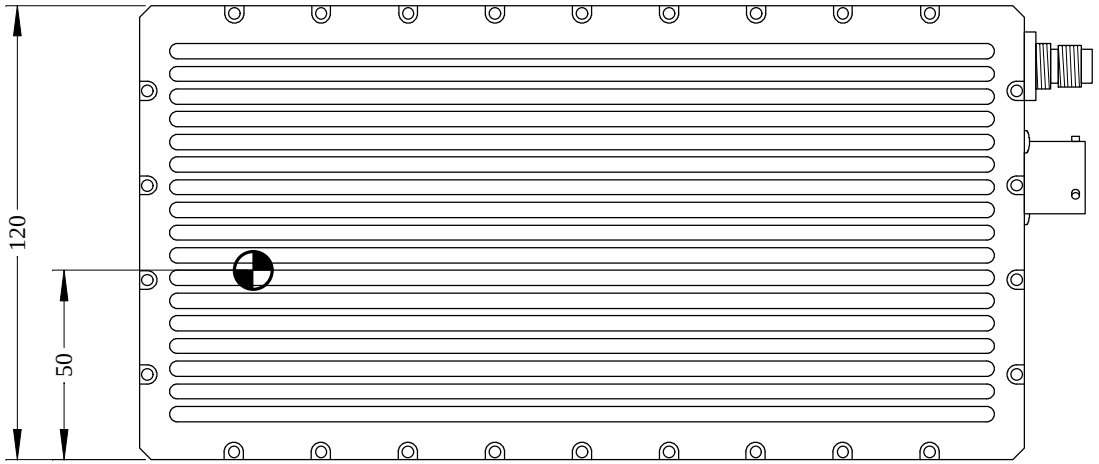

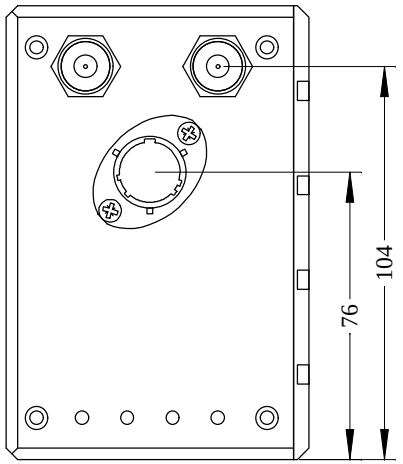

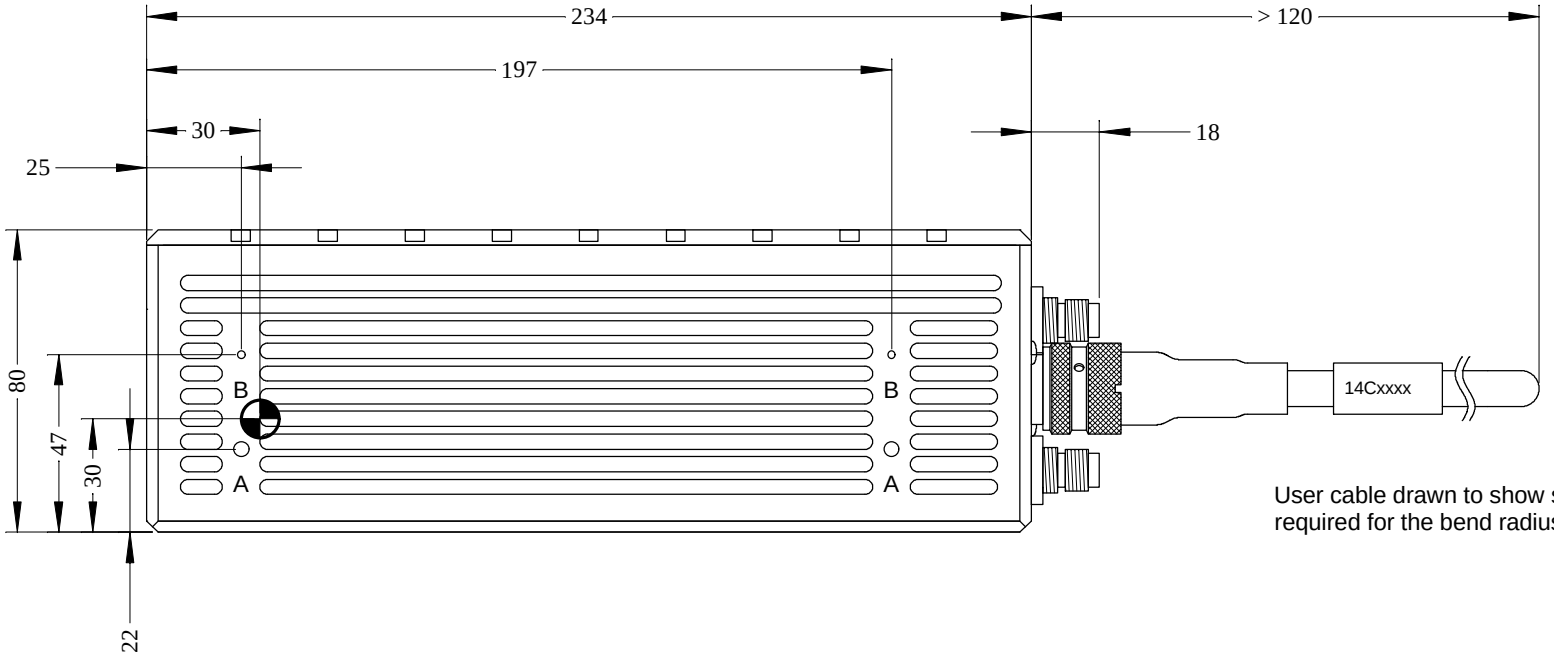

User cable drawn to show space required for the bend radius.

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0 10 20 30

Print Size:	A4
Scale:	1:2 (Half)
Units:	mm
Tolerances:	X.X – 0.1
Projection:	3rd Angle
Material:	HE30 Alu
Finish:	Anodised

Notes:

A – M4 x 10 Tapped Hole
B – 2mm dia x 3 hole

Edit History:

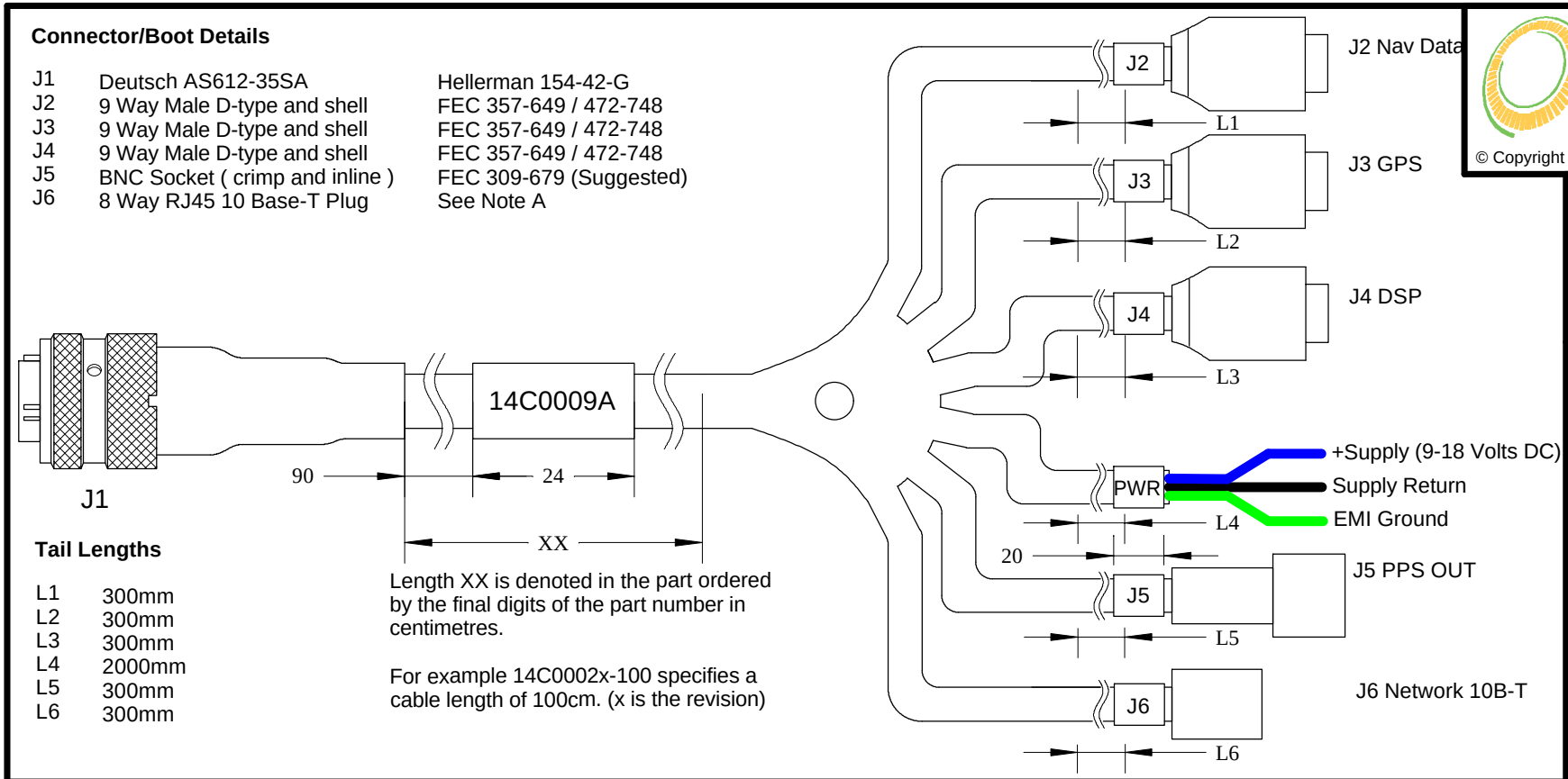
Date:	08/11/01
Part #:	14A0007A

Document:
RT3003 Outer Dimensions

Sheet: 1 of 1

Connector/Boot Details

J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9 Way Male D-type and shell	FEC 357-649 / 472-748
J3	9 Way Male D-type and shell	FEC 357-649 / 472-748
J4	9 Way Male D-type and shell	FEC 357-649 / 472-748
J5	BNC Socket (crimp and inline)	FEC 309-679 (Suggested)
J6	8 Way RJ45 10 Base-T Plug	See Note A



Tail Lengths

L1	300mm
L2	300mm
L3	300mm
L4	2000mm
L5	300mm
L6	300mm

Length XX is denoted in the part ordered by the final digits of the part number in centimetres.

For example 14C0002x-100 specifies a cable length of 100cm. (x is the revision)

Connection/Cable Details

J1		J1	
1	+ Supply (16/02 Blue)	12	J2 - Pin 5 - RS232 Common
2	Supply Return (16/02 Black)	13	J6 - Pin 2
3	J2 - Pin 3 - Nav Data RS232 TX	14	J6 - Pin 6
4	J2 - Pin 2 - Nav Data RS232 RX	15	N/C
5	N/C	16	J3 - Pin 5 - RS232 Common
6	J3 - Pin 3 - GPS Data RS232 TX	17	J4 - Pin 5 - RS232 Common
7	J3 - Pin 2 - GPS Data RS232 RX	18	J5 - PPS out GND (Screen)
8	N/C	19	N/C
9	J4 - Pin 3 - DSP Data RS232 TX	20	J6 - Pin 1
10	J4 - Pin 2 - DSP Data RS232 RX	21	J6 - Pin 3
11	J5 - PPS out (Centre conductor)	22	EMI Ground (Green)

Special Notes

Cable outers braided and connected to EMI Ground.

J1 13-20 Twisted, see NOTE A.
J1 14-21 Twisted, see NOTE A.

NOTE A: J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1, FEC 480-125 will make two assys.

Power cores 1,2 and 22 16/02, All other signals 7/02.

PPS OUT connector to be screened cable, whose screen is isolated from the outer EMI braid. The screen connects to PPS Ground, and the centre conductor connects to PPS Out.

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0 10 20 30

Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

Notes:

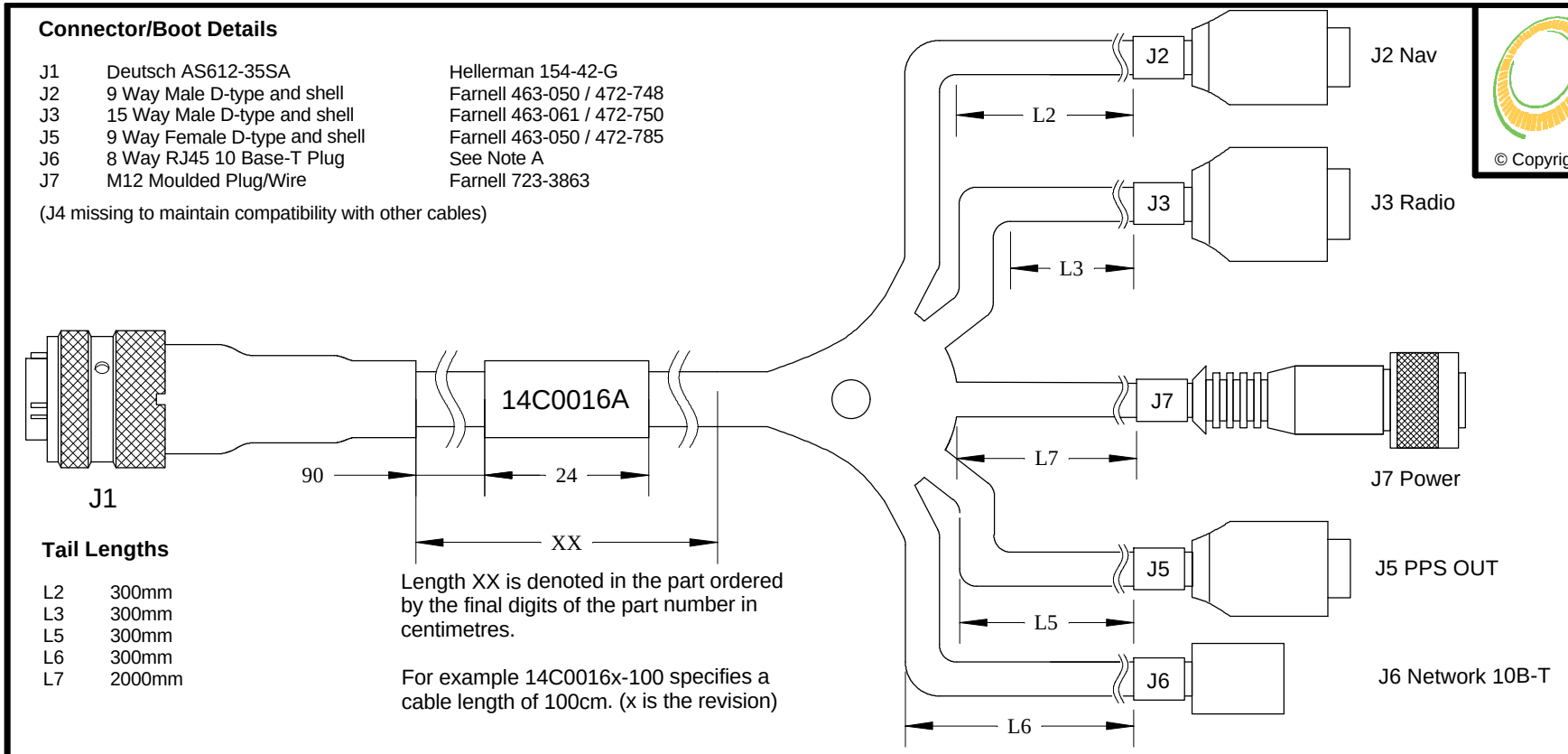
Edit History:

Date:	27/11/00
Part #:	14C0009A
Document:	RT3000 User Cable
Sheet:	1 of 1

Connector/Boot Details

J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9 Way Male D-type and shell	Farnell 463-050 / 472-748
J3	15 Way Male D-type and shell	Farnell 463-061 / 472-750
J5	9 Way Female D-type and shell	Farnell 463-050 / 472-785
J6	8 Way RJ45 10 Base-T Plug	See Note A
J7	M12 Moulded Plug/Wire	Farnell 723-3863

(J4 missing to maintain compatibility with other cables)



Tail Lengths

L2	300mm
L3	300mm
L5	300mm
L6	300mm
L7	2000mm

Length XX is denoted in the part ordered by the final digits of the part number in centimetres.

For example 14C0016x-100 specifies a cable length of 100cm. (x is the revision)

Connection/Cable Details

Description	Wire	J1	Connections
Power Supply (10 to 18V D.C.)	16/02	1	J7-1 (Brown), J3-14, J3-15, J3-1
Power Return (0v, Ground)	16/02	2	J7-3 (Blue), J3-7, J3-8
Nav Data RS232 TX	7/02	3	J2-3
Nav Data RS232 RX	7/02	4	J2-2
N/C	7/02	5	N/C
GPS Data RS232 TX	7/02	6	J3-11
GPS Data RS232 RX	7/02	7	J3-9
N/C	7/02	8	N/C
DSP Data RS232 TX	7/02	9	N/C
DSP Data RS232 RX	7/02	10	N/C
PPS RS422-A	7/02	11	J5-2
Nav Data RS232 Common	7/02	12	J2-5
Ethernet (ETX-)	7/02	13	J6-2
Ethernet (ERX-)	7/02	14	J6-6
N/C	7/02	15	N/C
GPS Data RS232 Common	7/02	16	J3-7
DSP Data RS232 Common	7/02	17	N/C
PPS RS422 Common	7/02	18	J5-5
PP2 RS422-B	7/02	19	J5-7
Ethernet (ETX+)	7/02	20	J6-1
Ethernet (ERX+)	7/02	21	J6-3
Case/Earth	16/02	22	J7-4 (Black)

Special Notes

All Cable outers braided and connected to EMI Ground apart from J7 where no braid exists)

J1 13-20 Twisted, see NOTE A.
J1 14-21 Twisted, see NOTE A.

NOTE A: J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1, FEC 480-125 will make two assys.

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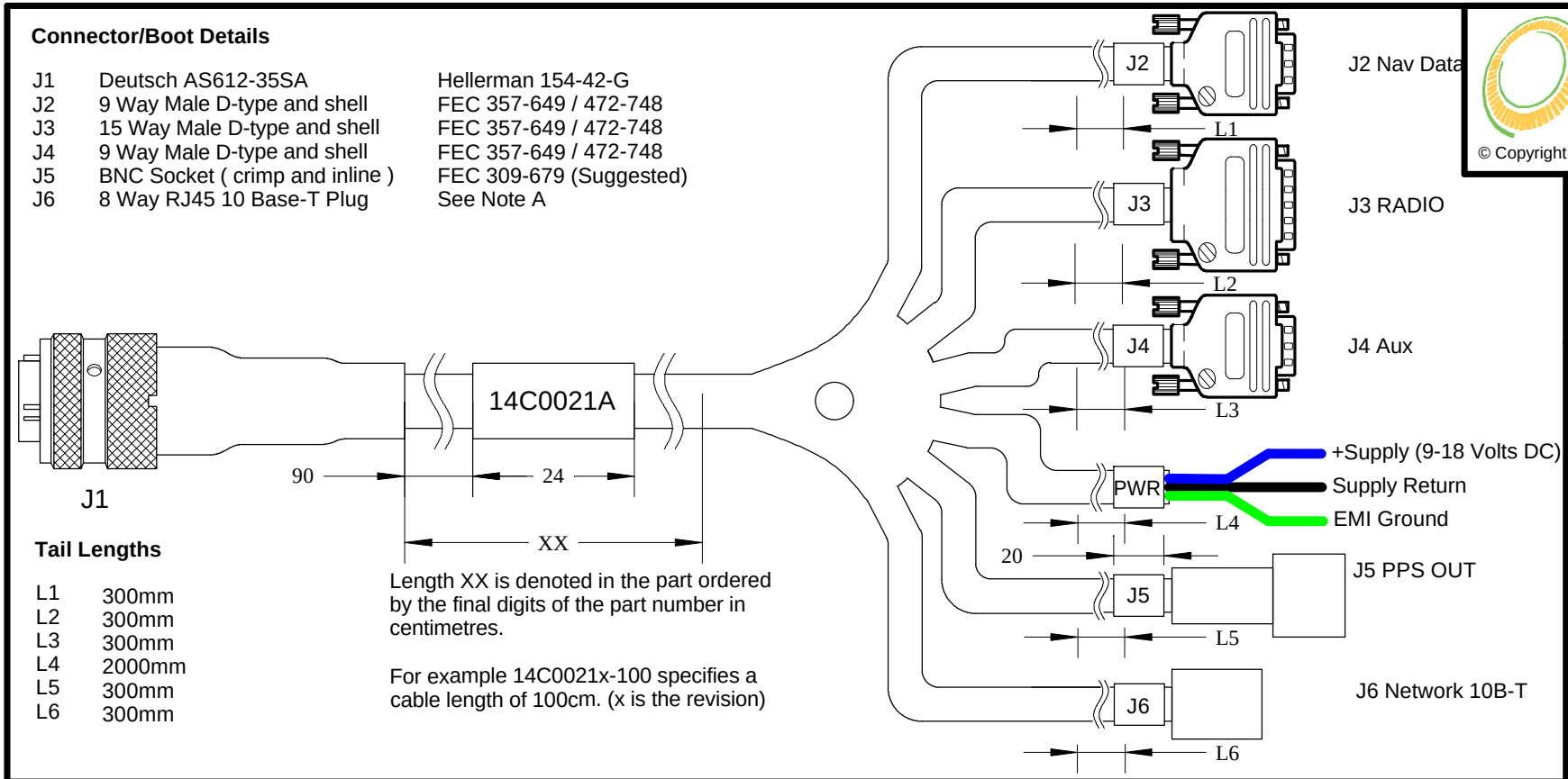
0 10 20 30

Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	10mm
Projection:	N/A
Notes:	
Date:	08/11/01
Part #:	14C0016A
Document:	RT3000 User Radio Cable
Sheet:	1 of 1

Connector/Boot Details

J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9 Way Male D-type and shell	FEC 357-649 / 472-748
J3	15 Way Male D-type and shell	FEC 357-649 / 472-748
J4	9 Way Male D-type and shell	FEC 357-649 / 472-748
J5	BNC Socket (crimp and inline)	FEC 309-679 (Suggested)
J6	8 Way RJ45 10 Base-T Plug	See Note A



Tail Lengths

L1	300mm
L2	300mm
L3	300mm
L4	2000mm
L5	300mm
L6	300mm

Length XX is denoted in the part ordered by the final digits of the part number in centimetres.

For example 14C0021x-100 specifies a cable length of 100cm. (x is the revision)

Connection/Cable Details

Description	J1	Connections
+Supply (Blue) (16/0.2)	1	J3-1,J3-14,J3-15,PWR-Blue
Supply Return (Black) (16/0.2)	2	J3-7,J3-8,PWR-Black
Nav Data RS232 TX	3	J2-3
Nav Data RS232 RX	4	J2-2
N/C	5	N/C
Radio Data RS232 TX	6	J3-11
Radio Data RS232 RX	7	J3-9
N/C	8	N/C
Aux Data RS232 TX	9	J4-3
Aux Data RS232 RX	10	J4-2
PPS out (Centre Conductor)	11	J5-CORE
Nav Data RS232 Common	12	J2-5
Ethernet (ETX-)	13	J6-2
Ethernet (ERX-)	14	J6-6
N/C	15	N/C
Radio Data RS232 Common	16	J3-7
Aux Data RS232 Common	17	J4-5
PPS out GND (Screen)	18	J5-SCREEN
N/C	19	N/C
Ethernet (ETX+)	20	J6-1
Ethernet (ERX+)	21	J6-3
EMI Ground (Green) (16/0.2)	22	PWR-Green

Special Notes

Cable outers braided and connected to EMI Ground.

J1 13-20 Twisted, see NOTE A.
J1 14-21 Twisted, see NOTE A.

Power cores 1,2 and 22 16/02, All other signals 7/02.

PPS OUT connector to be screened cable, whose screen is isolated from the outer EMI braid. The screen connects to PPS Ground, and the centre conductor connects to PPS Out.

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0 10 20 30

Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

Notes:

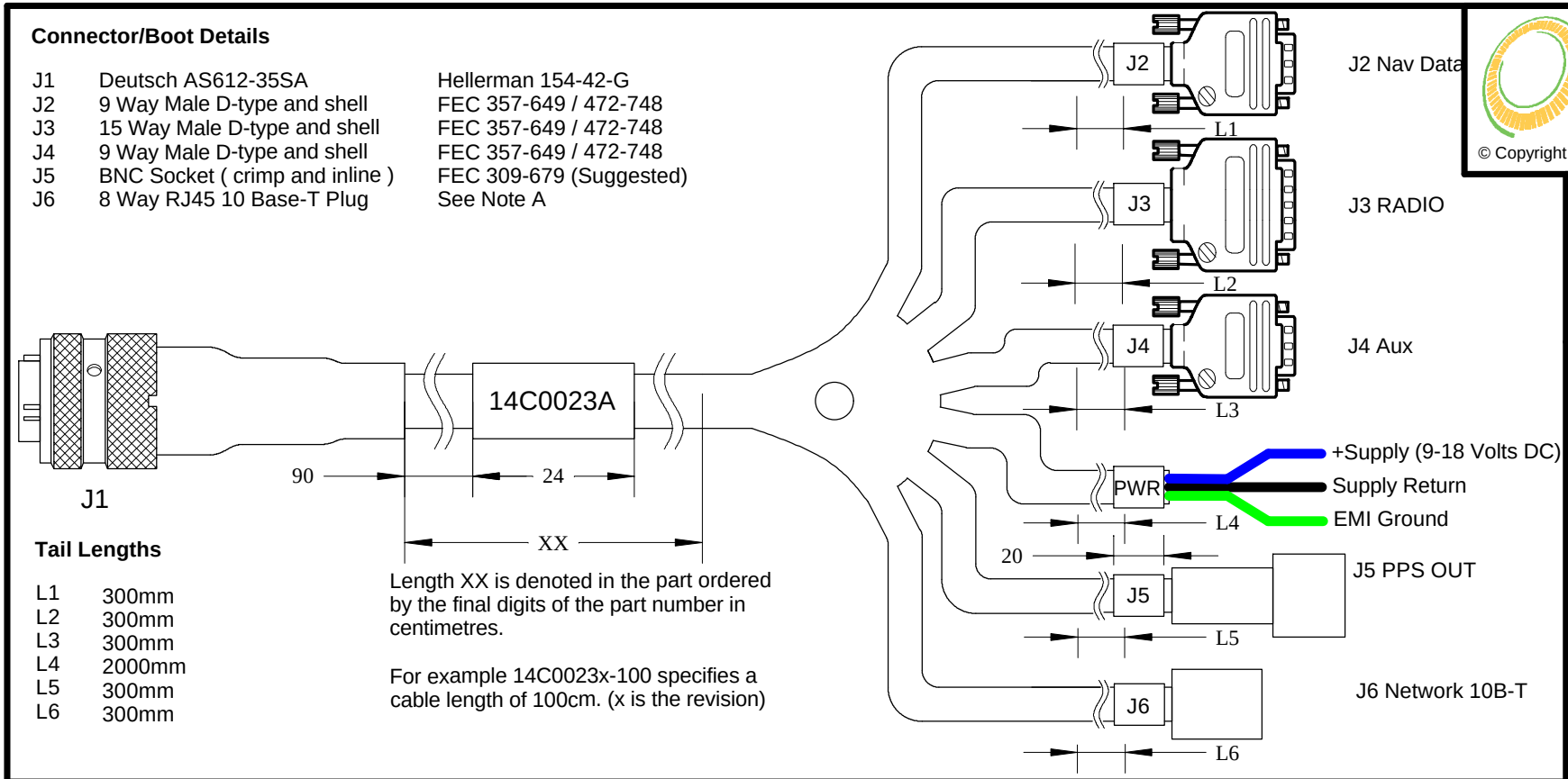
NOTE A:
J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1, FEC 480-125 will make two assys.

Edit History:

Date:	26/04/02
Part #:	14C0021A
Document:	RT3000 User Cable
Sheet:	1 of 1

Connector/Boot Details

J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9 Way Male D-type and shell	FEC 357-649 / 472-748
J3	15 Way Male D-type and shell	FEC 357-649 / 472-748
J4	9 Way Male D-type and shell	FEC 357-649 / 472-748
J5	BNC Socket (crimp and inline)	FEC 309-679 (Suggested)
J6	8 Way RJ45 10 Base-T Plug	See Note A



Tail Lengths

L1	300mm
L2	300mm
L3	300mm
L4	2000mm
L5	300mm
L6	300mm

Length XX is denoted in the part ordered by the final digits of the part number in centimetres.

For example 14C0023x-100 specifies a cable length of 100cm. (x is the revision)

Connection/Cable Details

Description	J1	Connections
+Supply (Blue) (16/0.2)	1	J3-1,J3-14,J3-15,PWR-Blue
Supply Return (Black) (16/0.2)	2	J3-7,J3-8,PWR-Black
Nav Data RS422 TX+	3	J2-2
Nav Data RS422 RX+	4	J2-7
Nav Data RS422 TX-	5	J2-1
Radio Data RS232 TX	6	J3-11
Radio Data RS232 RX	7	J3-9
N/C	8	N/C
Aux Data RS232 TX	9	J4-3
Aux Data RS232 RX	10	J4-2
PPS out (Centre Conductor)	11	J5-CORE
Nav Data RS422 Common	12	J2-5
Ethernet (ETX-)	13	J6-2
Ethernet (ERX-)	14	J6-6
Nav Data RS422 RX-	15	J2-6
Radio Data RS232 Common	16	J3-7
Aux Data RS232 Common	17	J4-5
PPS out GND (Screen)	18	J5-SCREEN
N/C	19	N/C
Ethernet (ETX+)	20	J6-1
Ethernet (ERX+)	21	J6-3
EMI Ground (Green) (16/0.2)	22	PWR-Green

Special Notes

Cable outers braided and connected to EMI Ground.

J1 13-20 Twisted, see NOTE A.
J1 14-21 Twisted, see NOTE A.

Power cores 1,2 and 22 16/02, All other signals 7/02.

PPS OUT connector to be screened cable, whose screen is isolated from the outer EMI braid. The screen connects to PPS Ground, and the centre conductor connects to PPS Out.

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Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

Notes:

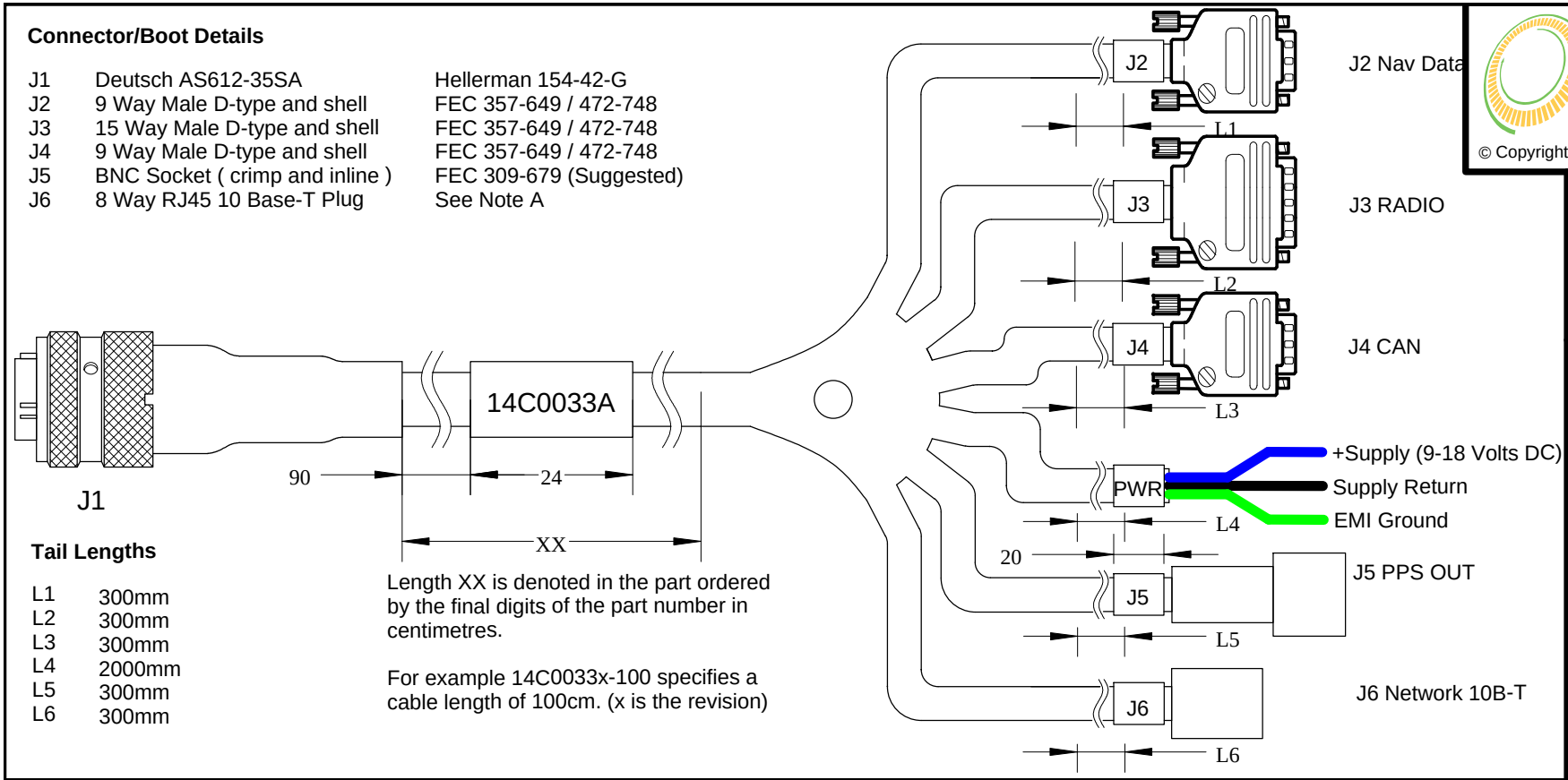
NOTE A:
J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1, FEC 480-125 will make two assys.

Edit History:

Date:	02/05/02
Part #:	14C0023A
Document:	RT3000 User Cable
Sheet:	1 of 1

Connector/Boot Details

J1	Deutsch AS612-35SA	Hellerman 154-42-G
J2	9 Way Male D-type and shell	FEC 357-649 / 472-748
J3	15 Way Male D-type and shell	FEC 357-649 / 472-748
J4	9 Way Male D-type and shell	FEC 357-649 / 472-748
J5	BNC Socket (crimp and inline)	FEC 309-679 (Suggested)
J6	8 Way RJ45 10 Base-T Plug	See Note A



Tail Lengths

L1	300mm
L2	300mm
L3	300mm
L4	2000mm
L5	300mm
L6	300mm

Length XX is denoted in the part ordered by the final digits of the part number in centimetres.

For example 14C0033x-100 specifies a cable length of 100cm. (x is the revision)

Connection/Cable Details

Description	J1	Connections
+Supply (Blue) (16/0.2)	1	J3-1,J3-14,J3-15,PWR-Blue
Supply Return (Black) (16/0.2)	2	J3-7,J3-8,PWR-Black
Nav Data RS232 TX	3	J2-3
Nav Data RS232 RX	4	J2-2
N/C	5	N/C
Radio Data RS232 TX	6	J3-11
Radio Data RS232 RX	7	J3-9
N/C	8	N/C
CAN+	9	J4-7
CAN-	10	J4-2
PPS out (Centre Conductor)	11	J5-CORE
Nav Data RS232 Common	12	J2-5
Ethernet (ETX-)	13	J6-2
Ethernet (ERX-)	14	J6-6
N/C	15	N/C
Radio Data RS232 Common	16	J3-7
CAN GND	17	J4-6, J4-3
PPS out GND (Screen)	18	J5-SCREEN
N/C	19	N/C
Ethernet (ETX+)	20	J6-1
Ethernet (ERX+)	21	J6-3
EMI Ground (Green) (16/0.2)	22	PWR-Green

Special Notes

Cable outers braided and connected to EMI Ground.

J1 13-20 Twisted, see NOTE A.
J1 14-21 Twisted, see NOTE A.

Power cores 1,2 and 22 16/02, All other signals 7/02.

PPS OUT connector to be screened cable, whose screen is isolated from the outer EMI braid. The screen connects to PPS Ground, and the centre conductor connects to PPS Out.

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Print Size:	A4
Scale:	Not to scale
Units:	mm
Tolerances:	5mm
Projection:	N/A

Notes:

NOTE A:
J6 is a RJ45 UTP patch lead which is cut to length and terminated at J1, FEC 480-125 will make two assys.

Edit History:

Date:	06/10/03
Part #:	14C0033A
Document:	RT3000 User Cable (CAN)
Sheet:	1 of 1

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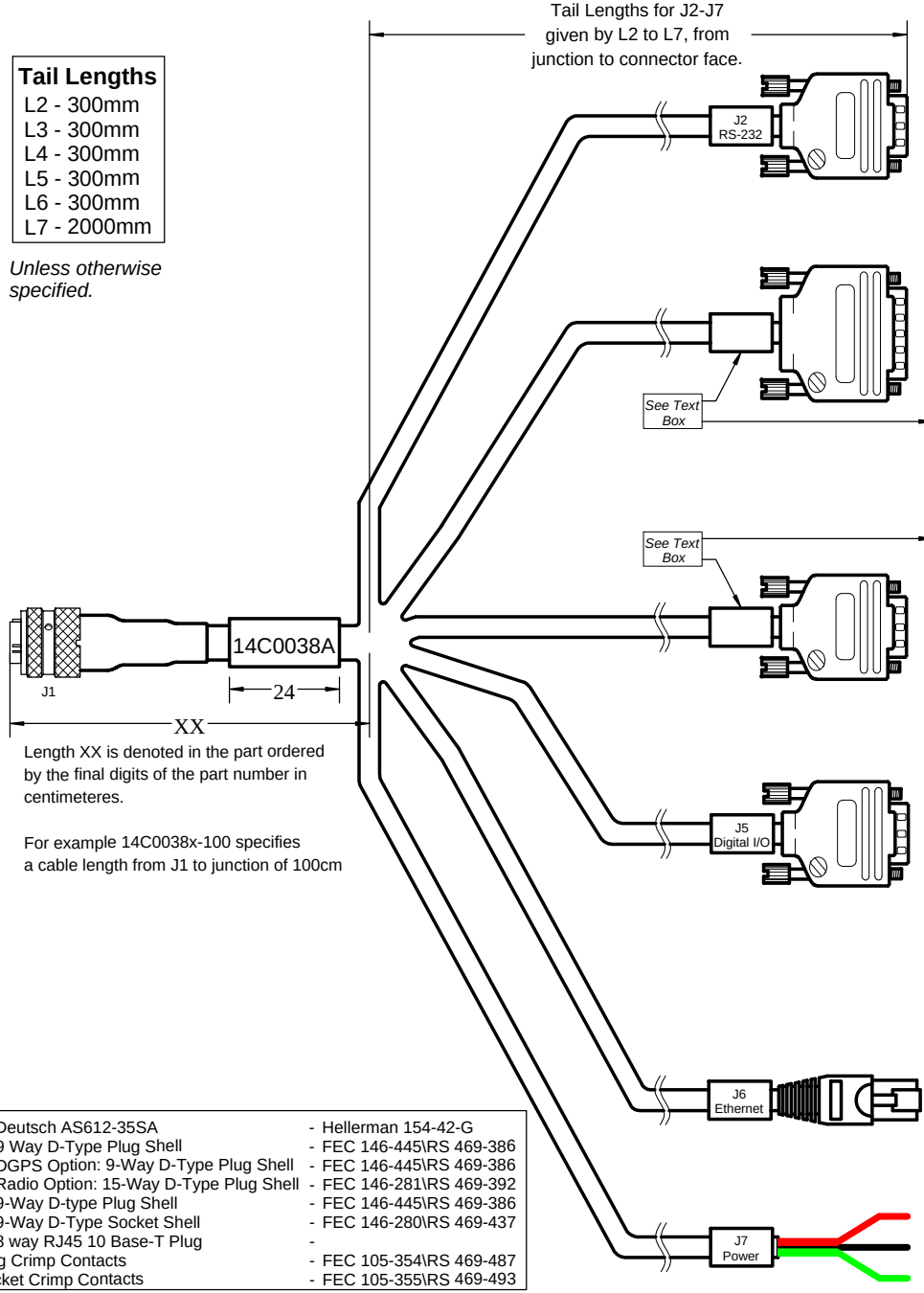
Tail Lengths
L2 - 300mm
L3 - 300mm
L4 - 300mm
L5 - 300mm
L6 - 300mm
L7 - 2000mm

Unless otherwise specified.



Length XX is denoted in the part ordered by the final digits of the part number in centimeteres.

For example 14C0038x-100 specifies a cable length from J1 to junction of 100cm

J1 Deutsch AS612-35SA	-	Hellerman 154-42-G
J2 9 Way D-Type Plug Shell	-	FEC 146-445\RS 469-386
J3 DGPS Option: 9-Way D-Type Plug Shell	-	FEC 146-445\RS 469-386
J3 Radio Option: 15-Way D-Type Plug Shell	-	FEC 146-281\RS 469-392
J4 9-Way D-type Plug Shell	-	FEC 146-445\RS 469-386
J5 9-Way D-Type Socket Shell	-	FEC 146-280\RS 469-437
J6 8 way RJ45 10 Base-T Plug	-	
Plug Crimp Contacts	-	FEC 105-354\RS 469-487
Socket Crimp Contacts	-	FEC 105-355\RS 469-493

Pin	Function	Conn
2	Nav Data RS232 RX	J1-4
3	Nav Data RS232 TX	J1-3
5	RS232 Common	J1-12

DEFAULT OPTION: Radio

Pin	Function	Conn
1	+Supply	J3-14
7	RS232 Common	J1-16
8	Supply Return	J7-2
9	Radio Data RX	J1-7
11	Radio Data TX	J1-6
14	+Supply	J7-1
15	+Supply	J7-1

15-Way Plug Shell

Cable Legend	J3 Radio

OPTION: DGPS

Pin	Function	Conn
2	GPS Data RS232 RX	J1-7
3	GPS Data RS232 TX	J1-6
5	RS232 Common	J1-16
	Sleeved and made safe	J7-1
	Sleeved and made safe	J7-2

9-Way Plug Shell

Cable Legend	J3 DGPS

DEFAULT OPTION: CAN

Pin	Function	Conn
2	CAN-	J1-10
3	CAN Gnd	J1-17
6	CAN Gnd	J4-3
7	CAN +	J1-9

9-Way Plug Shell

Cable Legend	J4 CAN

OPTION: RS-232

Pin	Function	Conn
2	Aux Data RX	J1-10
3	Aux Data TX	J1-9
5	Common	J1-17

9-Way Plug Shell

Cable Legend	J4 Aux RS232

Digital I/O

Pin	Function	Conn
1	Digital 1	J1-11
2	Digital 2	J1-8
3	Digital 3	J1-15
4	Digital 4	J1-19
5	Digital 5	J1-5
6	Digital Ground	J1-18
7	Digital Ground	J1-18
8	Digital Ground	J1-18
9	Digital Ground	J1-18

See manual for details of the signals on Digital 1 to Digital 5

Pin	Function	Conn
1	Ethernet (ETX+)	J1-20
2	Ethernet (ETX-)	J1-13
3	Ethernet (ERX+)	J1-21
6	Ethernet (ERX-)	J1-14

Pin	Colour	Function	Conn
1	Red	+Supply (9-18 Volts DC)	J1-1
2	Black	Supply Return	J1-2
3	Green	EMI Ground	J1-22

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Print Size: A4

Scale: Not to Scale

Units: mm

Tolerances: 5mm

Notes:

Ensure that cable legend text precisely matches that given in diagram.

Wire Types:
J7-1, J7-2, J7-3 16/0.2
All other signals 7/0.2.

Please populate all unused pins on D-types with empty crimps.

Cable outers braided and connected to EMI Ground

J1-13 & J1-20 Twisted Pair
J1-14 & J1-21 Twisted Pair

Date: 10/08/04

Part #: 14C0038A

Document: RT3000 User Cable

Sheet: 1 of 1

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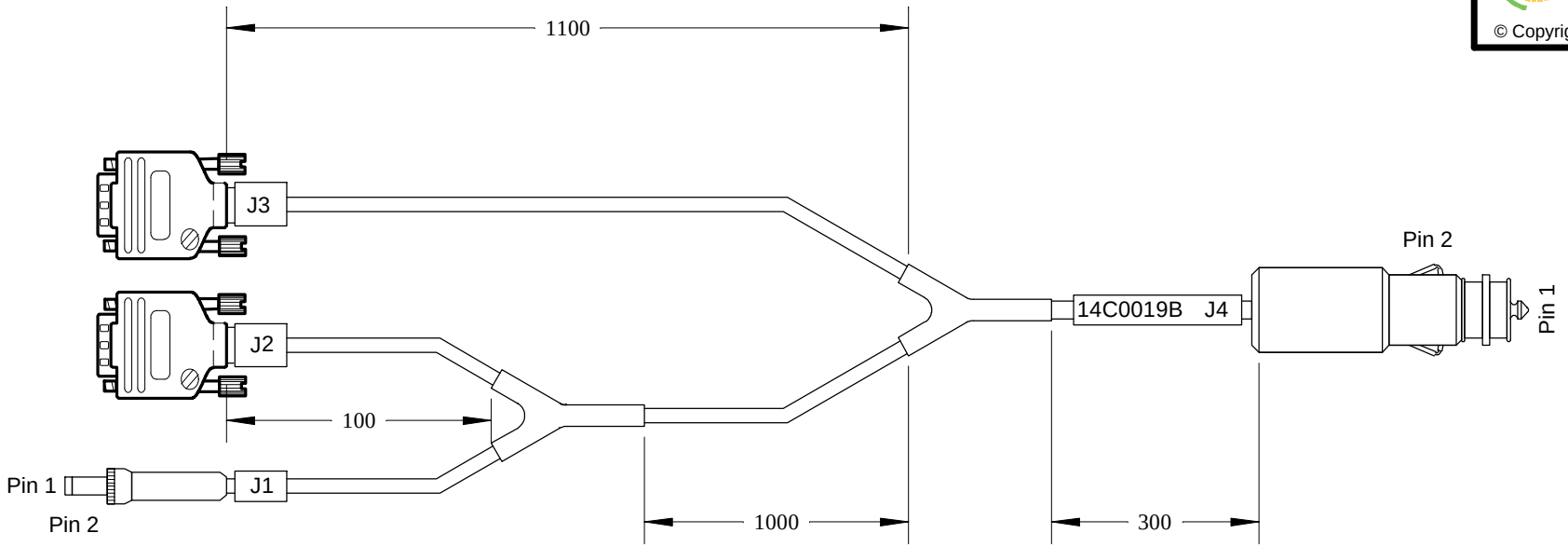

Connections

VS+: J4-1 to J1-1, J3-14, J3-15, J3-1 using blue 16/02 wire
GND: J4-2 to J1-2, J3-7, J3-8, J2-5 using black 16/02 wire
TX: J2-3 to J3-11 using 7/02 wire

Parts

J1	2.1mm Locking Power Jack, 12mm stem	See Note ii)
J2	9-way Female D-type and shell	FEC 472-785/472-748
J3	15-way Male D-type and shell	FEC 463-061/472-750
J4	Cigarette Lighter Socket	FEC 658-376

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Print Size:	A4
Scale:	1:1
Units:	mm
Tolerances:	10.0
Projection:	3rd Angle
Notes:	
Date:	29/05/02
Part #:	14C0019C
Document:	Radio Modem Base
Sheet:	1 of 1

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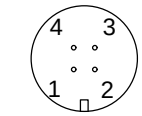
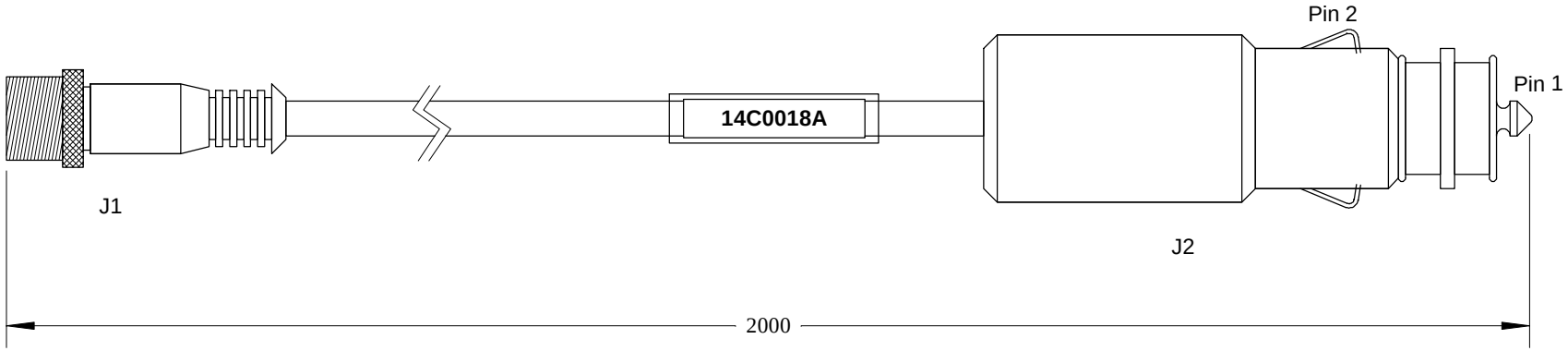


View from front of plug

Pin Definitions

J1-1 (Brown) Positive 12V Power supply (9–18 d.c.)
J1-2 (White) Not Used
J1-3 (Blue) 0V/GND
J1-4 (Black) Earth/Case



Parts

RS290-6512 M12 4w 2m PUR straight Connector
RS266-0250 Car Cigarette Lighter Plug
RS399-524 Yellow Heat Shrink 6.4mm
RS399-934 Clear Heat Shrink 6.4mm

Connections

J1-1 (Brown) – J2-1
J1-2 (White) – Not Connected
J1-3 (Blue) – J2-2
J1-4 (Black) – J2-2

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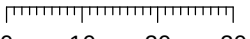

Print Size:	A4
Scale:	1:1
Units:	mm
Tolerances:	100mm
Projection:	N/A
Notes:	
Date:	07/12/01
Part #:	14C0018A
Document:	M12 Power Cable
Sheet:	1 of 1

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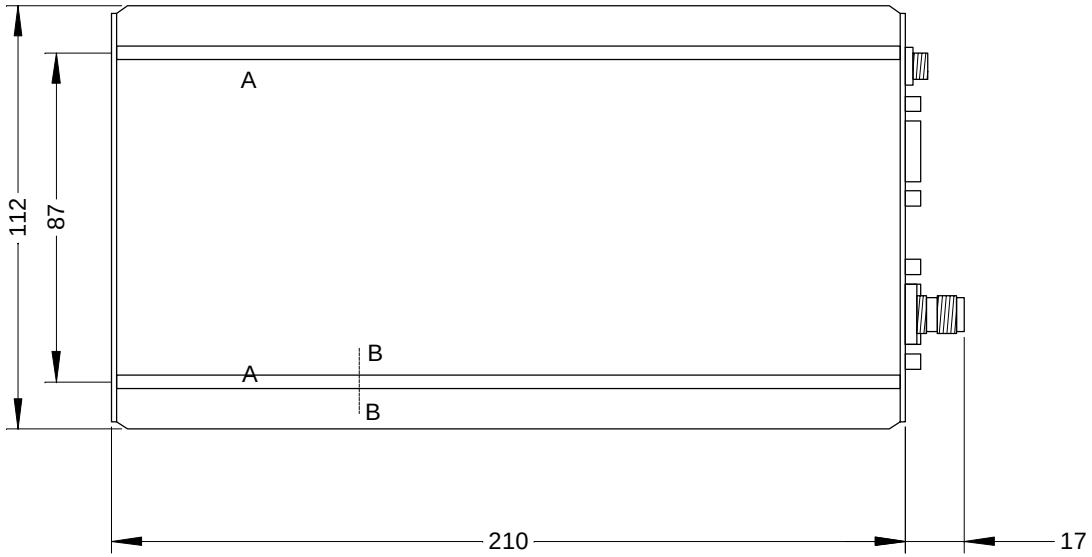
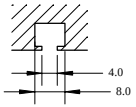
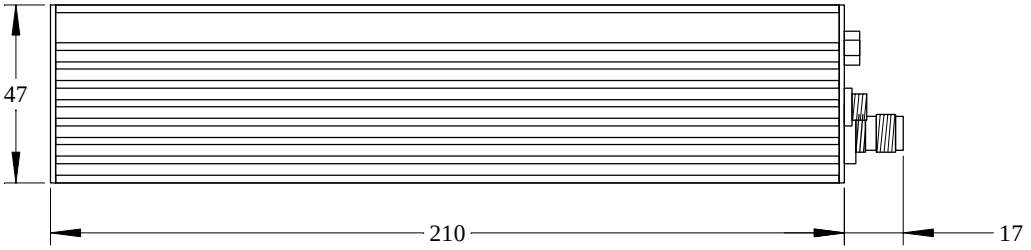


Section through B-B





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0 10 20 30

Print Size:	A4
Scale:	1:2 (Half)
Units:	mm
Tolerances:	X.X – 0.1
Projection:	3rd Angle
Material:	Alu
Finish:	Painted

Notes:

A – Channel for Mounting

Edit History:

Date:	08/11/01
Part #:	N/A

Document:
Novatel Power-Pak-II

Sheet: 1 of 1

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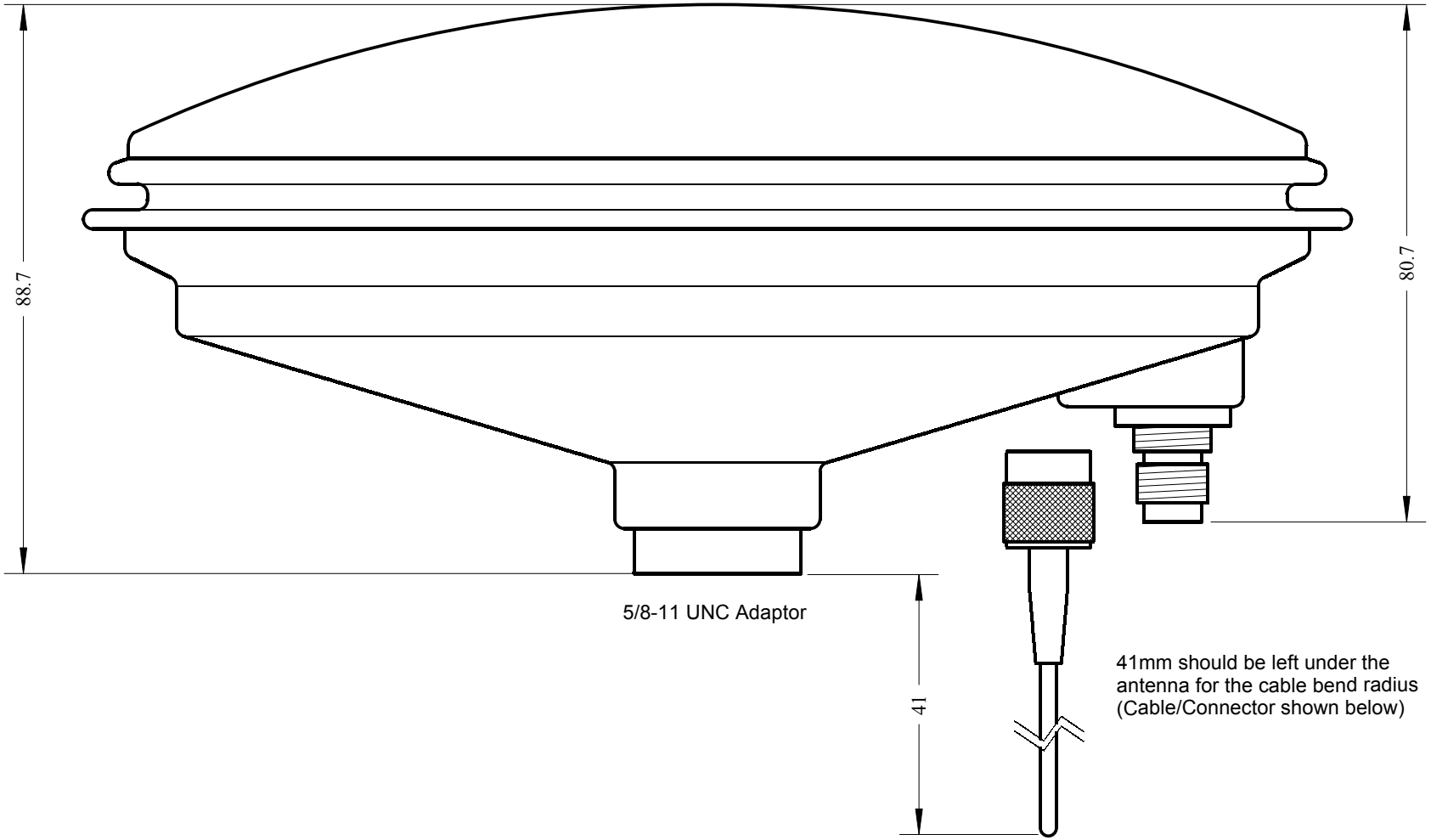

0 10 20 30

Print Size:	A4
Scale:	1:1
Units:	mm
Tolerances:	1mm
Projection:	3rd Angle

Notes:

L1 Ant. – Blue Rim
L1/L2 Ant. – Black Rim

Date:	08/11/01
Part #:	GPS-600
Document:	Novatel GPS Antenna
Sheet:	1 of 1

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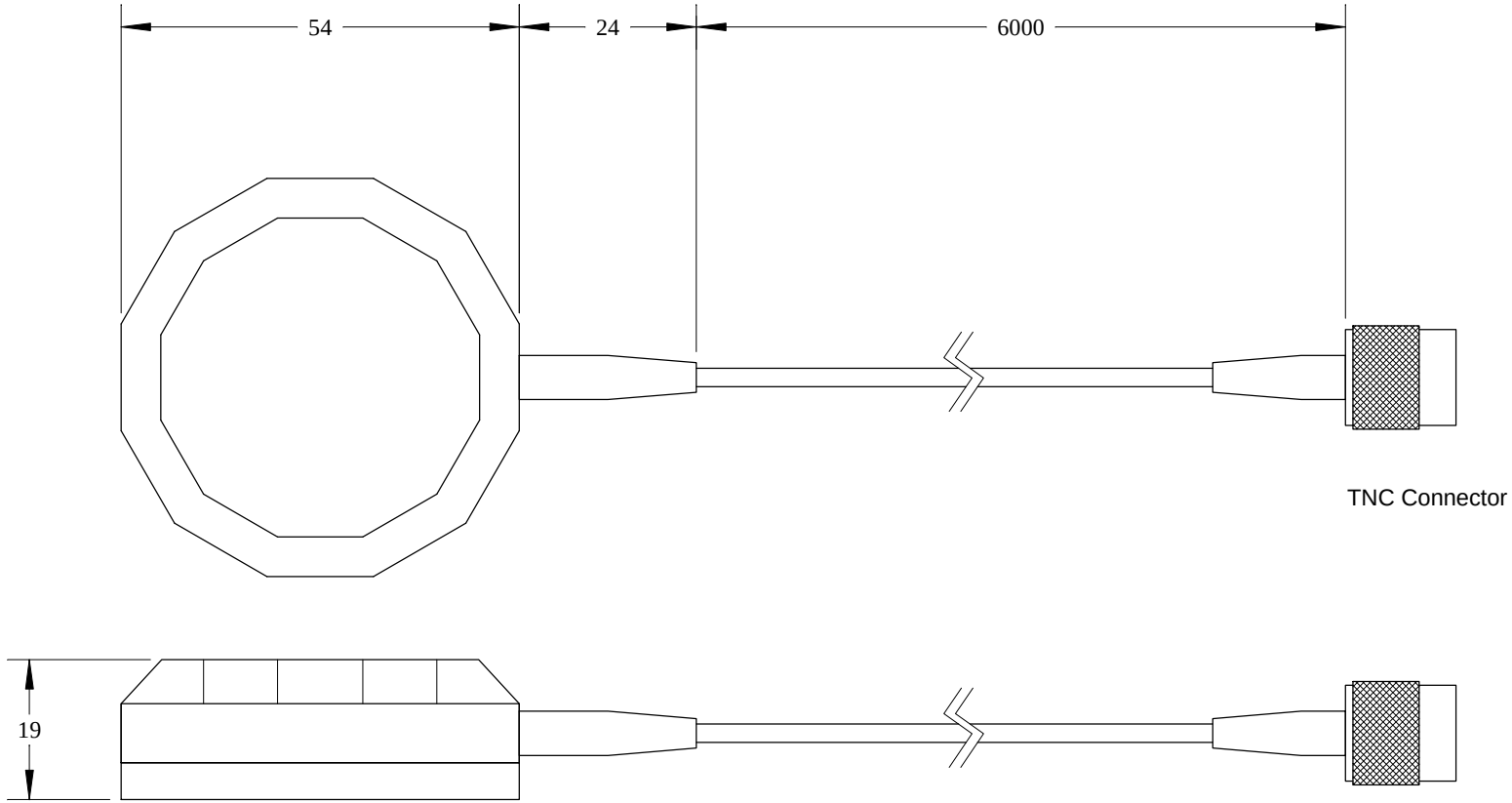

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Print Size:	A4
Scale:	1:1
Units:	mm
Tolerances:	1 mm
Projection:	3rd Angle
Notes:	
Date:	21/08/01
Part #:	201-990146-789
Document:	Magnetic GPS Antenna
Sheet:	1 of 1